White Paper No. 8 – Habitat and Ecological Considerations as a Remedy Component for the Lower Fox River

Response to a Review of

Baseline Human Health and Ecological Risk Assessment: Lower Fox River and Green Bay, Wisconsin Remedial Investigation and Feasibility Study

October 2001

This document has been prepared by

Wisconsin Department of Natural Resources

December 2002

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

During the comment period, comments were received expressing concern that the remedial activities defined in the *Proposed Remedial Action Plan, Lower Fox River and Green Bay* (Proposed Plan) (WDNR and EPA, 2001) would adversely impact the aquatic resources of the Lower Fox River. These commenters stated that the Proposed Plan lacked both a quantitative and qualitative assessment of the potential ecosystem damage, and that the remedial activities would result in loss of habitat. Specifically, impacts to submerged aquatic vegetation (SAV), loss of substrate material (i.e., gravel and snags), fish food sources, and decreases in fish populations were cited as adverse responses to dredging. As part of the comments to the Proposed Plan, the Appleton Papers, Inc. Panel (API Panel) submitted a report entitled *Ecosystem-Based Rehabilitation Plan – An Integrated Plan for Habitat Enhancement and Expedited Exposure Reduction in the Lower Fox River and Green Bay* (Panel Report) (The Johnson Company, 2002) in which capping was offered as a potential remedial alternative, concluding that it resulted in habitat enhancement. In response, this White Paper presents an assessment of the current habitat conditions and an analysis of potential ecosystem damage from remedial activities including an analysis of the benefits of dredging versus capping. The analyses presented here show that both dredging and capping should have minimal adverse impact on aquatic communities. However, capping, in itself, would not provide a habitat enhancement due to short-term negative environmental impacts in suppressing benthic populations. Further, cobble material used in high-flow areas would refill with silt and would not create fish breeding areas. Additional conclusions drawn from the assessment were that potential impacts to habitat would be a consideration when selecting remedial actions. And, while not a component of the remedial design, restoration would be conducted separately under the Natural Resource Damage Assessment (NRDA) settlement.

1 INTRODUCTION

1.1 PURPOSE

This White Paper considers habitat and/or fisheries-related issues associated with proposed remedy components for the Lower Fox River. Active management of approximately 2,400 acres of river bottom is being considered for the Lower Fox River by the Wisconsin Department of Natural Resources (WDNR) and the United States Environmental Protection Agency (EPA). While the WDNR and EPA's Proposed Plan (WDNR and EPA, 2001) marked those areas for dredging, a final Record of Decision may in fact be an integrated management program, combining dredging, capping, and natural attenuation to achieve management goals.

Dredging and capping are important components of assessing any remedial alternative for the Lower Fox River and Green Bay. This is reflected in the *Remedial Investigation for the Lower Fox River and Green Bay, Wisconsin* (RI) (RETEC, 2002a) and *Feasibility Study for the Lower Fox River and Green Bay, Wisconsin* (FS) (RETEC, 2002b), the Panel Report (The Johnson Company, 2002) prepared on behalf of Appleton Papers, Inc., (API) and in the response prepared on behalf of the Fox River Group (FRG) and associated companies to the RI/FS. One criticism of dredging is that removal of sediments alters the biological communities and removes the base of the food chain, as well as potential nursery habitat for juvenile fish. Opponents of capping argue that placement of artificial substrate in a depositional environment adversely effects the base of the food chain and provides little to no additional benefit to existing fish species. Clean material could and should attract benthic invertebrates and other aquatic species to utilize the area. This clean material overlays contaminated materials. Animals attracted to this new area may be exposed to contaminated materials below the surface, by borrowing or eating prey items that can burrow into the contaminated material below.

This White Paper evaluates these issues by examining the scientific literature, individual case studies, and data collected for the Lower Fox River. The objective is to realistically characterize where potential habitat impacts may occur within the River, to evaluate whether these issues have been of concern at other sites, and then to determine if there are ways to mitigate those concerns if impacts will occur.

The White Paper draws on extensive previous experience and work done by the United States Army Corps of Engineers (USACE), experience by WDNR and University of Wisconsin, Madison fisheries biologists and limnologists, and habitat maps prepared by both the National Oceanic and Atmospheric Administration (NOAA) and Exponent (1999).

This White Paper will focus on the potential for those impacts within the Operable Units (OUs) that may be impacted by remedial alternatives.

The key points contained in this report are as follows:

1. Potential impacts to habitat should be a consideration when selecting remedial actions, but restoration is not a remedial action objective (RAO).

2. Dredging and capping, both locally and nationally, has been shown to have minimal impact on aquatic communities.

3. Both dredging and capping have the potential to resuspend sediments, but the levels of resuspended solids and PCBs are lower than those naturally occurring on the Lower Fox River.

4. Benthic invertebrates are in low diversity in the Lower Fox River and, as evidenced by the case studies provided, recovery may occur quickly in depositional areas of the Lower Fox River following dredging activities.

5. Marsh habitat is an important and sparse asset on the Lower Fox River. Any remedial alternative should weigh the environmental risks from PCBs left in place to the risks of loss of habitat.

6. Fish will not be affected by any of the proposed remedial alternatives.

7. The type of habitat enhancements consistently called for by WDNR and the Proposed Plan are those that would support the diversification of the fish assemblages within the River, and the creation of more nearshore, shallow littoral habitat.

1.2 EFFECTS

An important issue to consider is the effect of any active sediment management operation on the associated aquatic species within the Lower Fox River. Remedial effects associated with dredging have been well studied and documented (Allen and Hardy, 1980; Clarke and Wilber, 2000; Guannel et al., 2002; Snyder, 1976; USACE, 2002). The effects examined have included numerous studies in the scientific and regulatory community ranging from resuspension, substrate and depth changes, particle settling, in-water disposal, noise (in- and above-water), chemical releases, fish entrainment in dredge equipment, and changes in habitat and community structure.

The majority of research conducted on the habitat effects of dredging has been in relation to dredged material disposal (Hirsch et al., 1978; LaSalle et al., 1991). The body of literature describing the recovery of the remaining sediment following dredging, especially in freshwater systems, is far less substantial. However, many studies discuss recovery following other types of disturbances. The effects of disturbances like dredging may be short-term or long-term depending on the nature of the impact, stream type, biotic group, and timing of the disturbance (Milner, 1994; Niemi et al., 1990; Detenbeck et al., 1992). Direct effects of dredging may include injury or mortality of benthos, fish, and wildlife, or loss of habitat (Pearson, 1984; Carline and Brynildson, 1977; Harvey and Lisle, 1998; Larson and Moehl, 1990; Armstrong et al., 1981). Substrate changes, removal of refugia (cover), and loss of in-stream and streamside vegetation may also result in indirect impacts to aquatic and aquatic-dependent organisms. Indirect effects may include reduction of abundance and diversity of benthos, fish, and wildlife, and change in habitat characteristics resulting from altered physical or chemical habitat or food sources (Yount and Niemi, 1990; Carline and Brynildson, 1977; Simpson et al., 1982). Effects to and recovery of aquatic communities following disturbance events are generally evaluated by comparing the condition of unstressed, surrounding areas to source areas.

The USACE has been concerned with documenting and identifying ways of managing the environmental effects associated with removal and capping operations since the early 1970s. Much of this research has been compiled by the USACE in a web-accessible format. The E2-D2 (Environmental Effects & Dredging and Disposal) literature database includes technical references covering a diverse range of topics related to environmental effects of dredging and dredged material disposal projects (http://www.wes.army.mil/el/e2d2/index.html). As currently configured, E2-D2 contains approximately 3,000 references.

The principal impacts that are of concern for the Lower Fox River for any active remedial alternative include

- Impacts to water column aquatic biota from sediment resuspended during dredging or capping operations;
- Impacts to benthic biota from sediment removal or capping;
- Alterations to SAV;
- Impacts to fish species during and after dredging operations; and
- Alterations to critical habitat for benthos or fish species.

2 CRITICAL HABITAT AND BIOTA

This section of this White Paper reviews the variables associated with recovery of aquatic habitats following disturbance events like dredging and capping, to identify and summarize site-specific studies that investigated habitat recovery following disturbance, and to apply principles derived from these studies to the specific habitat characteristics and proposed remedy of the Lower Fox River system. The Lower Fox River habitat and food web are summarized in order to consider how the habitat may recover from the effects of dredging, based on pilot studies conducted in the Lower Fox River and literature-derived scientific studies.

Each of the River reaches has been deemed a separate OU (OUs 1 through 4). An OU is a geographical area designated for the purpose of analyzing remedial actions, usually on the basis of uniform properties and characteristics throughout the OU. The River reaches and corresponding OUs are:

- **OU 1 –** Little Lake Butte des Morts;
- **OU 2 –** Appleton to Little Rapids Reach;
- **OU 3 –** Little Rapids to De Pere Reach; and
- **OU 4 –** De Pere to Green Bay Reach.

Descriptions of the aquatic and terrestrial habitats that occur in each of the four Lower Fox River OUs are included along with a review of the organisms that make up the food web within the River. The amount and type of aquatic, terrestrial, and fringe habitats present may have a direct or indirect influence on the effects of dredging and the recovery of each habitat following dredging. Different habitats recover from disturbances like dredging at different rates. Understanding important variables like the distribution of substrate types and sizes and the distribution of SAV are important parameters that influence the types of organisms that make up the benthic and aquatic communities.

2.1 LOWER FOX RIVER HABITAT

The Lower Fox River is the largest Green Bay tributary based on both discharge and drainage area (6,330 square miles). Many dams and locks exist in the assessment area that serve to change the functional ecology of the Lower Fox River system into a system that is more characteristic of a series of lakes and pools (WDNR, 1994). The River narrows to as little as 150 meters and widens to more than 300 meters in Little Lake Butte des Morts. Little Lake Butte des Morts (OU 1) is characterized by slower velocities and is more similar to a lentic (lake) system than any of the other three Lower Fox River OUs. OU 2, from Appleton to Little Rapids, is a narrow, channelized reach with high velocities. OU 3, from Little Rapids to the De Pere dam, and OU 4, from the De Pere dam to Green Bay, each contain a variety of faster flowing areas and slower, pooled environments.

A variety of habitats are present in the Lower Fox River and on the buffer of terrestrial vegetation adjacent to the River (i.e., riparian zone). For the purposes of this report, the habitats for each of the four OUs are characterized in terms of SAV and substrate distribution. Brief summaries are provided describing the shoreline type and terrestrial habitats adjacent to the River. Habitat information is taken from investigations conducted by Exponent in summer and fall of 1998 (Exponent, 1998), and from wetland surveys conducted by NOAA and the United States Fish and Wildlife Service (USFWS). Detail for all wetland habitat types within the Lower Fox River and Green Bay are presented in the RI (RETEC, 2002a).

2.1.1 Little Lake Butte des Morts – OU 1

Little Lake Butte des Morts is a wide stretch of River with a small flow gradient, yielding slower flow velocities than much of the River. It makes up approximately 900,000 square meters of habitat for fish and wildlife. Much of its shoreline is composed of riprap (53 percent) and bulkhead piling (17 percent). Natural shoreline, comprised of cover by canopy and undeveloped open areas, represents 32 percent of the total shoreline. The northwestern side of Little Lake Butte des Morts near the confluence of Mud Creek and in backwaters, coves, and tributary mouths are dominated by emergent wetlands. SAV is present in these areas at an estimated 60 percent of the total shoreline coverage. It is present in 48 percent of the open-water area of Little Lake Butte des Morts.

Approximately half of the substrate in the Little Lake Butte des Morts Reach is comprised of semi-compact sands and/or clay-type deposits. The remainder of the unit is composed of soft, aqueous, silty sediments and deposits of irregular, compact sand, gravel, and cobble. Much of the area is generally shallow; depths in the lake south of the Mud Creek confluence are generally less than 6 feet, and only achieve depths greater than 10 feet in the thalweg of the River. North of the Appleton dam, the River becomes narrower and deeper; up to 17 feet, but seldom exceeding 20 feet in overall depth. Table 1 provides summaries of the distribution of substrate types in each OU.

TABLE 1 LOWER FOX RIVER SUBSTRATE DISTRIBUTION

Type	Description	Little Lake Butte des Morts	Appleton to Little Rapids	Little Rapids to De Pere	De Pere to Green Bay
Type I	Soft, aqueous, silty sediments	30	15	85	95
Type II	Semi-compact to compact sands and/or clay	50	7	4	3
Type III	Compact sand, gravel, and cobble deposits	20	77	6	1
Type IV	Combination of Types I and II	0	0	4	2
Type V	Cobble and boulder-size rocks	0	< 1	< 1	0

Notes:
Percent estimates are based on a qualitative interpretation of the preliminary side-scan sonar results.

Estimates for each OU are averaged from estimates for corresponding areas as categorized in the original habitat characterization (Exponent, 1998).

Habitat uses within Little Lake Butte des Morts are seriously impaired due to the heavy loads of silt, phosphorus, and nitrogen from Lake Winnebago. All species within this reach are affected by siltation, which reduces the fish habitat. Little Lake Butte des Morts is also affected by serious algal blooms and is considered to be a hypereutrophic lake (WDNR, 2002a).

2.1.2 Appleton to Little Rapids – OU 2

The River narrows at Appleton and flow velocity increases; however, several dams and locks are present. A total of 41 percent of the shoreline of the upper portion of OU 2 is developed as residential and urban/commercial. Shoreline becomes more residential below Cedars Lock and primarily agricultural for the remainder of the reach until Little Rapids. The density of maintained properties of OU 2 allows for greater deadfall and overhang in the lower stretches than in the upper stretch. Natural shoreline with undisturbed canopy dominates in undeveloped areas.

Large clusters of uninhabited islands are present in the middle portion of OU 2, near the area of the Thousand Island Conservancy. These islands provide backwater habitat, shoreline access, and an extensive lock channel system used by fish and wildlife. Tributaries are present in each stretch; however, they are most common in the lower portion of OU 2. These tributaries provide small wetlands consisting of floating and narrow-leafed emergent vegetation that account for the majority of the sparse occurrence of SAV in shallow, slower-flowing areas.

Sand, gravel, and cobble are most common in OU 2. Only smaller patches of semi-compact sands and/or clay are scattered throughout the upper and lower portions of OU 2. Very small patches of cobble and boulder and one patch of soft, aqueous, silty sediment is present in a widened section in the middle of OU 2; however, almost the entire reach is composed of sand, gravel, and cobble common to faster flowing waters.

2.1.3 Little Rapids to De Pere – OU 3

The River widens following the Little Rapids Lock into an area fed by numerous tributaries that provide fish and wildlife habitat along only small areas of natural shoreline. Land use is mostly agricultural and becomes more residential and urban/commercial moving downstream near De Pere. Shoreline coverage is similar to that of Little Lake Butte des Morts, comprising nearly 50 percent of the total shoreline coverage. SAV is present in low abundance.

The area immediately below the Little Rapids dam is composed of riffle runs, but quickly becomes quiescent and shallow, with depths averaging 5 to 8 feet. As the River narrows toward De Pere, the habitat becomes more channelized, but characterized by deeper water and slower flow velocities. Compact sand and gravel sediment present in the riffle area transitions to a mix of soft, aqueous, silty sediments and compact sands and clays, followed by an area of soft, aqueous, silty sediment for the remainder of the reach. Few structural attributes such as island networks, lock channels, and bridge abutments are present in OU 3, with less diverse habitat types compared to other parts of the Lower Fox River.

2.1.4 De Pere to Green Bay – OU 4

Virtually all of the shoreline of OU 4 is developed as industrial, commercial, or residential development. The most important characteristic of the area is the pronounced reduction in natural shoreline cover when compared to the other parts of the River. Few wetlands are present due to the urban nature of the reach. Bulkhead piling and riprap are more common in this reach than any of the other reaches. Natural shoreline constitutes only 12 percent of the total shoreline from the Mason Street Bridge to the mouth of the Lower Fox River but is slightly more common upstream to the De Pere dam.

Substrate of the River in this area is generally soft, aqueous silt, with very little cover of cobble or large rocks. A small portion of the substrate is associated with the dam riffle, comprised of compact sand, gravel, and cobble. SAV and emergent aquatic vegetation are in low density, present only in shallow coves and backwater areas. Water clarity is low. Water clarity is a function of both phytoplankton bloom and silt load in all reaches of the River. In addition, urban runoff can affect water clarity.

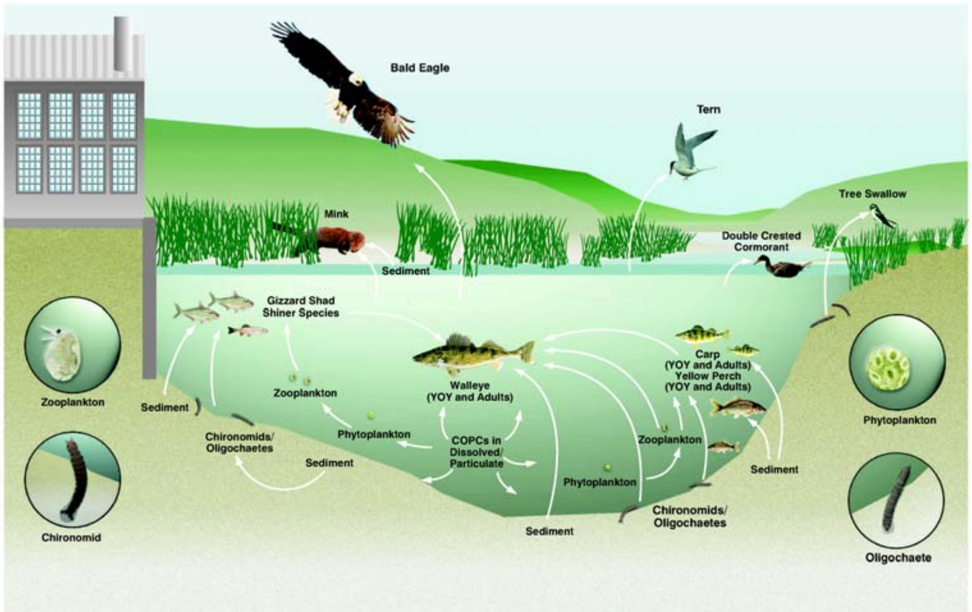
While the Lower Fox River widens immediately below the De Pere dam, the depths within the main channel of the River are generally greater than 10 feet of depth. Some shallow areas exist in the vicinity of the Brown County Fairgrounds and just immediately south of the Fort Howard facility. Beginning at approximately the Fort Howard facility, the River has been narrowed and channelized, with water depths now 20 to 30 feet through the navigation channel out into Green Bay.

2.2 FOOD WEB OF THE LOWER FOX RIVER

The Lower Fox River habitat supports a diverse community dependent on key variables such as water quality and depth, substrate distribution, and presence of SAV, among others. This section describes the habitat and groups of organisms constituting the communities present in the Lower Fox River. Furthermore, it describes the mechanisms of recolonization known for each organism group. These mechanisms are important in determining the rate at which the community and individual organisms recover following disturbance.

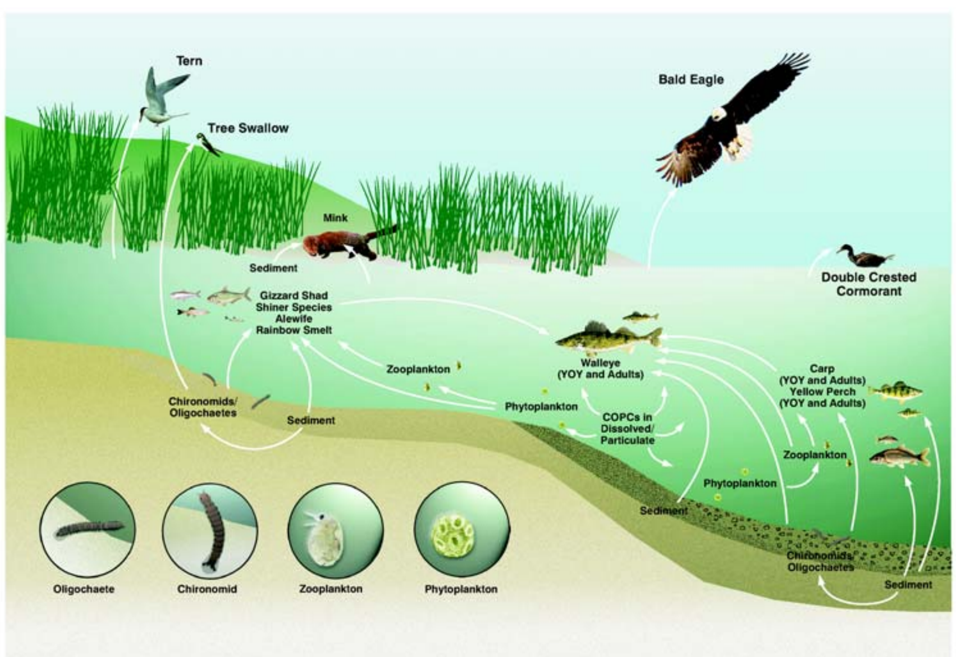
In order to understand the habitat issues, it is also important to understand the connections between the trophic structure present at the Site. The relationships between organisms at the base of the food chain and the fish and other organisms that feed upon them were defined by WDNR biologists (WDNR, 2001) for the RI/FS. The important consideration for habitat effects from dredging or capping is that the Lower Fox River functions as a pelagic food chain; that is, the food chain rests upon organisms within the water column and not on organisms living in the sediments. The food chain for the mouth of Lake Winnebago to the De Pere dam is shown on Figure 1. A second model was developed for below the De Pere dam through Green Bay Zone 2 (Figure 2). The De Pere dam restricts movement of Green Bay alewife and rainbow smelt further up the Lower Fox River. The only differences in conceptual model receptor species between these three models are the fish. The organisms comprising these communities and their respective mechanisms of recovery are summarized below.

Figure 1 Food Web Model for the Lower Fox River from Little Lake Butte des Morts to the De Pere Dam



F:\PROJECTS\DOCS\4414\COMMENTS\RESPONSE TO COMMENTS\WHITE PAPERS\FORMATTED\WHITE PAPER NO 8 - HABITAT FIGURES.PDF

Figure 2 Food Web Model for the De Pere Dam through Green Bay Zone 2



F:\PROJECTS\DOCS\4414\COMMENTS\RESPONSE TO COMMENTS\WHITE PAPERS\FORMATTED\WHITE PAPER NO 8 - HABITAT FIGURES.PDF

2.2.1 Phytoplankton and Zooplankton

Pelagic communities inhabiting the water column include both phytoplankton and zooplankton. Throughout the Lower Fox River and Green Bay, the food chain rests upon phytoplankton production. Phytoplankton are small uni- or multi-cellular algae and form the base of the pelagic food chain. They are common throughout all reaches of the Lower Fox River and are consumed by both fish and some benthic and epibenthic invertebrates. Phytoplankton presence can be limited by nutrient and light availability, but are typically widespread in any aquatic environment (Wetzel, 1983). Phytoplankton thrive on nutrients in the water column that are present in the Lower Fox River in part because of their association with suspended sediments.

Primary producers in the water column (phytoplankton) and detritus, or decomposing organic matter, represent the first level of trophic structure. The next trophic level, primary consumers, includes zooplankton and benthic infauna that feed directly on the phytoplankton or detritus/organic carbon within the sediment. Depending on zooplankton population levels, phytoplankton levels can either be limited or overabundant. If phytoplankton become overabundant (i.e., they are not sufficiently grazed by zooplankton) then they eventually die, settle to the sediment surface, and, as detritus, become part of the benthic food chain. Decomposition in organically rich sediments can lead to oxygen-depleted (anoxic) sediment and overlying water.

As noted previously, the entire Lower Fox River system and large parts of Green Bay are considered to be eutrophic. In the late summer, thick mats of algae (*Chladophora* spp.) cover parts of Little Lake Butte des Morts, and result in depressed oxygen and poor water conditions that have resulted in frequent fish mortalities. Phytoplankton die-offs are also implicated as one causal factor in the annual avian botulism die-offs (WDNR, 2002a).

Relative levels of eutrophication are quantified by the Trophic State Index (TSI); a TSI greater than 50 is considered to be a highly eutrophic system. While there are no TSI data specific to Little Lake Butte des Morts, TSI data for Lake Winnebago at Menasha indicate that the TSIs are always above 50, and are as high as 77 (WDNR, 2002b). The southern part of Green Bay, including the section north of the De Pere dam, is also considered to be eutrophic. The Lower Fox River alone contributes over 75 percent of the total phosphorus load to Green Bay (Auer et al., 1985). In Lake Winnebago, the phytoplankton community appears to be nitrogen-limited in summer and is probably never phosphorus-limited (Gustin, 1995). About 40 percent of the annual inputs of phosphorus to the sediments are recycled. The intensity of the release rate of phosphorus depends on the rate of mineralization and the occurrence of lake-wide physical mixing events.

2.2.2 Emergent and Submerged Aquatic Vegetation (SAV)

There are two types of important aquatic vegetation in the Lower Fox River: SAV and emergent vegetation. SAV is a term used to describe rooted macrophytes typically found in shallow, nearshore waters that are wholly within the water. Examples of these plants include the common pondweed (*Potamogeton* spp.), water lilies (*Nyphaea* spp.), or Eurasian milfoil (*Myriophyllum spicatum*). Emergent vegetation are rooted within the River, but have a portion of their plant body above the water. Examples of emergent vegetation include cattails (*Typha* spp.) and bulrushes (*Scirpus* spp.). These plants form complex marsh systems that provide critical spawning, nursery, feeding, and/or cover habitat for many species of fish (Brazner and Magnuson, 1994). Typical emergent plants within the marshes of the Lower Fox River and Green Bay include bulrushes (*Scirpus* spp.), cattails (*Typha* spp.), arrowheads (*Sagittaria* spp.) and sedges (*Carex* spp.). Common submerged and floating species include *Potamogeton* spp. and water lilies (*Nyphae odorata* and *Nuphar variegatum*). These nearshore wetland habitats support a diverse fish assemblage that includes yellow perch, shiners, northern pike, bluegills, and largemouth bass. Water clarity and depth are limiting factors for the establishment of rooted aquatic macrophytes (Szymanski, 2000), and within the Lower Fox River system these are generally limited to areas that have less than 2 feet of water depth.

Freshwater marshes have also been identified as one of several critically imperiled communities in the Great Lakes (Nature Conservancy, 1994), and their maintenance has been adapted by the Great Lakes Remedial Action Plan as a central part of habitat restoration (Great Lakes RAP, 1996) play a pivotal role in the aquatic ecosystem of the Great Lakes, storing and cycling nutrients and organic material from the land into the aquatic food web. They sustain large numbers of common or regionally rare bird, mammal, reptile, and invertebrate species, including many land-based species that feed from the highly productive marshes. Most of the lakes' fish species depend upon them for some portion of their life cycles (Whillans, 1990), and large populations of migratory birds rely on them for staging and feeding areas.

Within the Lower Fox River, there are very few acres of rooted SAV marshes. As documented in the RI, approximately 825 acres of SAV are present in the Lower Fox River. Of these, 642 acres were present within Little Lake Butte des Morts, most associated with the Stroebe Island Marsh and other backwater wetlands. Within the Appleton to Little Rapids Reach (OU 2), there are 153 acres; most being associated with the Thousand Islands wetlands. There are 64 acres downstream of the Rapide Croche dam, and only 20 acres downstream of the De Pere dam (Exponent, 1998).

Reports of SAV in Little Lake Butte des Morts included descriptions of various species of pondweeds (*Potamogeton* spp.), waterweed (*Elodea nuttallii*), eel-grass or water celery (*Vallisneria americana*), and the water lilies (*Nyphaea* spp. and *Nuphar variegatum*). These species are located on the shallow edges and backwater coves. Large cattail stands (*Typha* spp.) are also identified near Stroebe Island where Mud Creek enters the Lower Fox River. The last remnant of northern pike spawning marsh is located along inside (west side) of Stroebe Island. Northern pike is an important predator species and WDNR has indicated that this spawning marsh should be protected from future dredging or fill (WDNR, 2002a).

What is not clearly identified in these reports is that the most prevalent SAV within Little Lake Butte des Morts is the undesired exotic Eurasian water milfoil (*Myriophyllum spicatum*). This introduced species annually forms huge monoculture stands with vast mats of surface foliage that shade out native aquatic plants and reduce oxygen content within the water. It is an opportunistic species that prefers lakes having a high load of nitrogen and phosphorous, which is also typical of Little Lake Butte des Morts.

There is a considerable body of literature that supports the position that the Eurasian water milfoil provides relatively little value as a habitat or food source for the native plants it replaces (USGS, 2002). The United States Geological Survey (USGS) scientific literature review determined that while milfoil will support epibenthic organisms, at high densities it has a low abundance and diversity of invertebrates, organisms that serve as fish food (Keast, 1984). The characteristics of Eurasian water milfoil's overabundant growth negate any short-term benefits it may provide fish in healthy waters. Dense cover allows high survival rates of young fish; however, larger predator fish lose foraging space and are less efficient at obtaining their prey (Lillie and Budd, 1992; Engel, 1995). Madsen et al. (1995) found growth and vigor of a warm-water fishery reduced by dense Eurasian water milfoil cover. The growth and senescence of thick vegetation depletes dissolved oxygen levels and degrades water quality (Honnell et al., 1992; Engel, 1995).

2.2.3 Benthic Organisms

The benthic macroinvertebrates in the Lower Fox River include adult and larval insects, mollusks, crustaceans, and worms. Given the predominance of fine-grained silt/clay sediments in the River, the predominant species are sediment-dwelling and burrow directly into the substrate for most of their life cycle. The benthic macroinvertebrate community plays an important role in ecosystem functions such as nutrient cycling and organic matter processing, and is a food resource for the benthic and pelagic fish communities.

Much of the benthic community surveys in the Lower Fox River sediment have shown low taxa richness and diversity with chironomids (midge larvae, Family Chironomidae) and oligochaetes (worms, Class Oligochaeta) dominating (IPS, 1993a, 1993b, 2000a, 2000b, 2000c; WDNR, 1996). Oligochaetes and chironomids are thought to be tolerant of organic enrichment and/or degraded habitats, whereas other species are less tolerant of enriched/degraded habitats (EPA, 1990).

Species of oligochaetes generally feed on decaying organic matter, including fine detritus, algae, and other microorganisms. The primary food for chironomids is planktonic algae and detritus. Chironomids and oligochaetes are normally found in greatest abundance in soft sediment deposits in pools, runs of streams, profundal areas and littoral areas of lakes with soft bottoms, and harbor or bay areas where stream-transported sediments have been deposited (Wetzel, 1983). River rock and riffle areas are not preferred habitat. Thus, within the Lower Fox River, removal of PCB-contaminated sediment would largely affect only these benthic communities.

Samples at some stations in the River have shown increased numbers of benthic invertebrates and increased diversity. For example, samples collected from Deposit POG in Little Lake Butte des Morts in 1994 were principally dominated by chironomids and oligochaetes, but also showed the presence of flatworms, sow bugs, amphipods (*Hyallela azteca*), clams (*Pisidium* spp.), and physid snails that had previously not been observed. However, this increase was only observed within Little Lake Butte des Morts; the remaining stations through the River remain low in diversity (IPS, 1994). The mayfly *Hexagenia bilineata* has been found below the De Pere dam, suggesting improvement in overall water quality (Cochran, 1992). However, these have only persisted at very low numbers, suggesting that recolonization is still limited by poor environmental conditions (Cochran and Kinziger, 1997).

The recovery of benthic invertebrates is complex due to differences in body size, reproductive techniques, mobility, and life span (Steinman and McIntire, 1990). Methods of recolonization usually depend on the types of migration sources. Four principal sources and mechanisms for stream benthos have been identified: (1) downstream migration or drift; (2) upstream migration; (3) vertical migration from within the substrate; and (4) aerial sources (Williams and Hynes, 1976; Williams, 1981). Not all migration sources are available in every aquatic system, but one or more are almost always present.

In general, downstream drift is typically the most important recovery mechanism of the benthos (Niemi et al., 1990; Minshall and Peterson, 1985). It is a particularly important relocating mechanism following disturbance for invertebrates that do not move far under their own power, such as relatively sedentary chironomids (Mackay, 1992). Chironomids are some of the earliest colonizers in experiments with newly placed bare substrates in streams (Waters, 1964; Gray and Fisher, 1981), in part because of their prominence in the drift (Waters, 1972).

Aerial colonization represents a major source for recovery, especially for large-scale disturbances like channel relocation. When other migration sources are unavailable, aerial colonization by invertebrates emerging from immature aquatic life stages can be very important. Chironomids, for example, have one or more generations per year in a population, maturing from egg, larva, and pupa aquatic life stages. They have been found to recolonize disturbed systems quickly thanks to their high dispersal abilities afforded by small wings and relatively light weight (Brundin, 1967). Other emergent invertebrates, like most Ephemeroptera (mayflies), Trichoptera (caddisflies), and many Plecoptera (stoneflies) are prevalent in the drift but considered weak fliers, while Odonata (dragonflies and damselflies), some Coleoptera (beetles), and Hemiptera (bugs) are good fliers (Williams, 1981). Molluscs are typically one of the last taxa to recover following disturbances (Wallace, 1990), presumably as a result of poor dispersal mechanisms.

2.2.4 Fish Species and Habitat Preferences

Fish in the Lower Fox River are largely dependent on water column organisms for food – a pelagic- rather than benthic-based food web (WDNR, 2001). Most secondary fish consumers depend on phytoplankton and zooplankton, and higher consumers rely on other fish. Multiple fish population surveys of the Lower Fox River have been completed to date. Fish catch results from these studies are summarized in the *Baseline Human Health and Ecological Risk Assessment for the Lower Fox River and Green Bay, Wisconsin, Remedial Investigation and Feasibility Study* (BLRA), but include at least 43 different fish species upstream of the De Pere dam (RETEC, 2002c). Twenty-four (24) were game fish and 19 species were non-game fish (as defined by state statute). This section touches briefly on the general composition of fish present in the Lower Fox River, and focuses more specifically on four groups of fish: carp, centrarchids, perch, and walleye.

General Fish Distributions within the River

Population results for Little Lake Butte des Morts indicate that game fish typically comprise about 30 to 40 percent of the fish captured (RETEC, 2002c). Yellow perch, walleye, white bass, and bullheads have all been the dominant game fish species at one point or another. Carp (a non-game fish) was the most prevalent fish observed in the Lower Fox River upstream of the De Pere dam. Carp typically account for 50 to 90 percent of non-game fish and approximately 50 to 60 percent of all fish captured in the surveys.

In the De Pere to Green Bay Reach, game fish account for 70 to 90 percent of the total captured fish population. The dominant game fish typically include yellow perch, one of the primary commercial species in the Bay, as well as walleye, white bass, and white perch. Walleye is another game fish that generally comprises more than 10 percent of the total fish population (RETEC, 2002c). Non-game fish below the De Pere dam are predominantly carp, white sucker, drum, and quillback.

Fish species are generally well distributed and use all areas of the last reach of the River (OU 4). Depending on the season and location of food items, all of the six named species can be found nearer the De Pere dam (OU 4), or within the channelized portion (OU 4). Adult walleye, as an example, are frequently found associated with structure in OU 4 and pursue gizzard shad that can be found in all areas of the River. In fact, most of the seasoned anglers attempting to catch larger walleye focus on the shipping channel associated with submerged structures even during the spawning period because many large females can be found at these locations. Many of these sites are found in the downstream sections of OU 4. While it is true that the highest fishing pressure for walleye occurs during the spawning period, anglers seek walleye at other times of the year, particularly during late summer and fall. During the summer and fall, the downriver areas can be especially productive. Furthermore, flathead catfish are sought throughout the summer months and anglers frequently fish from shore for this species along the walkway in downtown Green Bay. White bass and white perch are particularly attracted to the many warm-water discharges that can be found in OU 4, especially during early spring and late fall.

Carp

Carp are a bottom-dwelling species in the family Cyprinidae. They tolerate turbidity, low dissolved oxygen, pollution, and rapid temperature changes better than most any other fish in North America (Becker, 1983). Although they are tolerant of a wide range of conditions, they prefer shallow lakes and streams that have abundant aquatic vegetation and are warm (Becker, 1983). Young-of-the-year (YOY) carp diets consist of phytoplankton and zooplankton, while adult carp consume chironomids, oligochaetes, and zooplankton (Scott and Crossman, 1973; Weber and Otis, 1984; Carlander, 1997).

An investigation of spawning carp in Lake Winnebago and nearby lakes determined that carp prefer to spawn in areas of shallow vegetated waters 0.15 to 1.2 meters deep (Weber and Otis, 1984). These preferences have been supported by other authors (Becker, 1983; Scott and Crossman, 1973). Carp eggs attach themselves to underwater vegetation, debris, or any other object to which the egg will adhere (USFWS, 1982). Spawning over areas with dense vegetation will increase the success of reproduction. Young carp also strongly associate with vegetation as protective cover in 15- to 30-cm deep water (Weber and Otis, 1984).

CENTRARCHIDS

The sunfish (Centrachidae) are an important family of game fish, which include the bluegill (*Lepomis macrochirus*), pumpkinseed, (*Lepomis gibbosus*), smallmouth bass (*Micropterus dolomieui*) and the largemouth bass (*Micropterus salmoides*). As documented in the RI, throughout the Lower Fox River these species are poorly represented in the fish community (RETEC, 2002a). Only smallmouth bass, and black crappie (*Pomoxis nigromaculatus*) are taken in any significant numbers in any of the River reaches.

The limiting factor for centrarchid production in the River is the general lack of rooted aquatic macrophyte beds that provide early life-stage habitat (Becker, 1983; Lychwick, 2002). The Green Bay RAP advocated for improved habitat in the form of extensive areas of rooted aquatics, indicating the importance of this type of habitat to the River and Bay. Within Little Lake Butte des Morts, the marsh areas surrounding Stroebe Island support centrarchids.

YELLOW PERCH

Yellow perch and walleye are members of the perch family (Percidae). Yellow perch prefer shoreline areas with sand, gravel, or muddy sediments, modest to moderate amount of rooted aquatic vegetation, and water depths of less than 10 meters in clear lakes (Becker, 1983; Scott and Crossman, 1973; USFWS, 1983). Yellow perch (YOY and adults) are highly associated with complex macrophyte beds (Weaver et al., 1997). Perch consume phytoplankton and zooplankton for food (Scott and Crossman, 1973; Weber and Otis, 1984; Exponent, 1999; Carlander, 1997).

Yellow perch spawn after ice-out in April or early May. During spawning, eggs are usually deposited in sheltered areas and are frequently draped over emergent and submerged vegetation or submerged brush in water depths of 0.6 to 3 meters. Rocks, sand, or gravel may be used when submerged vegetation is not available (USFWS, 1983). They may travel long distances during migration. Lake Winnebago perch may swim from 48 to 81 km up the Fox River before they reach suitable spawning habitat (Becker, 1983).

WALLEYE

Walleye are tolerant of a range of environmental conditions, particularly turbidity and low light, but less tolerant to low oxygen levels. As adults, they prefer quiet waters over sand, gravel, and mud substrates (Becker, 1983). Generally resting in deep, dark waters during the day, they migrate to rocky shoals and weed beds to feed at night. Walleye may become active during the day if it is cloudy or the waters are turbid (Becker, 1983). YOY fish can be found near the sediments in 6 to 10 meters of water (Scott and Crossman, 1973), but are present in surface waters up to lengths of 35 mm (WDNR, 1970). Schooling is common during feeding and spawning.

YOY are believed to eat mainly phytoplankton, including diatoms and blue-green algae (RETEC, 2002c). Juvenile walleye begin to feed on fish, including alewife and yellow perch. The diet of older walleye is dominated by prey fish. When prey fish are less abundant, the walleye will feed on benthic invertebrates (RETEC, 2002c).

The walleye fishery is particularly well established throughout the Fox River (Becker, 1983) basins. Walleye will spawn in flooded marsh areas adjacent to the River. The most important attribute of these marsh areas is to have inlets and outlets which provide a continuous flow of water over the spawning area (Becker, 1983). On lakes with inlet waterways, spawning occurs in inlet streams on gravel bottoms. In some places, walleyes spawn on flooded wetland vegetation (Becker, 1983). Preferred spawning habitat are shallow shoreline areas, shoals, riffles, and dam faces with rocky substrate and good water circulation from wave action and currents (USFWS, 1984). In lakes with rocky shorelines, the rocky, wave-washed shallows are the primary spawning grounds.

A wide variety of bottom substrates already exists in the Lower Fox River. Areas of cobble, gravel, sand, and soft substrate are found throughout the River. A wide range of species are currently effectively using available habitats. Spawning habitat may be limited to some extent for walleye and smallmouth bass in the Lower Fox River but both are reproducing in the River, with walleye being fairly successful. Walleye in the Lower Fox River and Green Bay prefer to spawn over large gravel and cobble with the greatest success occurring over 2- to 6-inch material. This material was successfully employed by the WDNR in construction of walleye spawning enhancement areas in the River below the De Pere dam.

3 ENVIRONMENTAL EFFECTS OF IN-WATER REMEDIAL ACTIONS

As discussed in the introductory section, effects on aquatic organisms from remedial actions for dredging and capping have been well studied and documented (Allen and Hardy, 1980; Clarke and Wilber, 2000; Guannel et al., 2002; Snyder, 1976; USACE, 2002). The effects examined have included numerous studies in the scientific and regulatory community ranging from resuspension, substrate and depth changes, particle settling, in-water disposal, noise (in- and above-water), chemical releases, fish entrainment in dredge equipment, and changes in habitat and community structure. Capping-induced changes can be similar, if one considers the effects of change in substrate type, changes in bottom elevation, and burial of benthic species. Chemical releases of contaminants during dredging are also possible from resuspension of fine-grained material, advective releases of porewater during native sediment compression, or major release during shear failure of underlying sediments during placement of heavier, overburdening cap sediments.

Aquatic disturbances produce changes in benthic and aquatic community structure that can persist for a few weeks to many decades (Detenbeck et al., 1992; Niemi et al., 1990). The rate of succession, or community changes that occur at a site following a disturbance, is influenced by many factors, including the physical habitat and size of the disturbed area. Organisms directly impacted by physical habitat changes are periphyton (attached algae), phytoplankton, vegetation, benthic macroinvertebrates, and fish.

While all of the impacts discussed above can and have occurred at other sites, the principal impacts that are of concern for the Lower Fox River are thought to be:

- Impacts to water column aquatic biota from sediment resuspended during dredging or capping operations;
- Changes to benthic biota from sediment removal or capping;
- Alterations to SAV; and
- Impacts to fish species during and after dredging operations.

This section examines the general scientific literature and case studies on effects from removal actions and capping.

3.1 ENVIRONMENTAL EFFECTS OF RESUSPENSION

The biological responses of aquatic organisms to dredging resuspension has recently been very well reviewed in three separate papers; Guannel et al. (2002) Clarke and Wilber (2000), and Herbich (2000). Rather than try to re-create that information here, only the salient information relative to the Lower Fox River is presented in this section. The reader is referred to those articles for details.

The effects of total suspended solids (TSS) on aquatic biota have been studied for a wide variety of marine and freshwater organisms. The general conclusion of those studies is that significant adverse impacts are not associated with typical dredging projects of uncontaminated materials, although some localized effects can occur at higher resuspended concentrations (Guannel et al., 2002). Those authors concluded that resuspended sediment concentrations caused by natural phenomena (floods, storms, winds, etc.) are often higher and of longer duration than those caused by dredging. Table 2 shows TSS associated with typical storm event flows at other sites, relative to TSS from storm events and dredging resuspension on the Lower Fox River. This is well documented in monitoring of the pilot dredging projects as well, where pre-dredging TSS measurements were more than double the levels observed during dredging (FRRAT, 2000). TSS concentrations in mg/L for demonstration projects on the Lower Fox River, as well as for other more typical concentrations at other projects is presented in Table 3, as reviewed by Guannel et al. (2002).

TABLE 2 TSS CONCENTRATIONS DUE TO NATURAL PHENOMENA ON THE FOX RIVER AND AS REVIEWED BY GUANNEL ET AL., 2002

Location	Maximum Resuspension Value (mg/L)
Fox River (WDNR, 1995)	357
San Francisco Bay	100–200 (tides)
Indian River Bay, Delaware	570.0
Chesapeake Bay	600.0
Bay of Fundy	3,000.0
Chesapeake Bay	10,000 (hurricane)
False Bay, Washington	10,000.0

TABLE 3 EXAMPLES OF TSS CONCENTRATIONS FOR DREDGES ON LOWER FOX RIVER DEMONSTRATION PROJECTS AND AS REVIEWED BY GUANNEL ET AL., 2002

Location	Background Concentrations (mg/L)	Maximum of Reported Mean Concentrations (mg/L)
Cutterhead Dredge		
Lower Fox River Deposit N Demonstration	24–56	58.0
Lower Fox River SMU 56/57	28–33	65.0
Corpus Christi Channel	39–209	Up to 580
Upper Mississippi	170.5	~170.5
Portland Harbor	No changes between background and dredge conditions	
San Francisco Bay, California	38–153	~100.0
Mobile Bay Ship Channel, Alabama	25–30	125.0
Clamshell Dredge		
San Francisco Bay, California	40.0	30–90
Long Beach Harbor Pier F	NA	28.0
Long Beach Harbor Pier B	NA	1,092.0
Los Angeles River Estuary Dredging Pilot Study*	2.0	11.0
Los Angeles River Estuary Dredging Pilot Study*	7.5	9.3

Note:
* Data not yet published.

Resuspension of contaminated sediments on aquatic biota has been more difficult to assess. PCBs at the levels reported in the two demonstration projects on the Lower Fox River will not have an immediate, acute effect on the aquatic organisms. The Risk Assessment for the Lower Fox River thoroughly documents the levels of PCBs that are acute or chronically toxic to aquatic biota. The monitoring conducted during the pilot dredging projects demonstrated that even remediation at the most highly contaminated site in the River, PCB concentration did not approach these levels nor were they very different than PCB concentrations that have been observed in the water column absent dredging activity.

3.2 ENVIRONMENTAL EFFECTS ON BIOTA, FISH, AND SAV DURING REMOVAL ACTIONS

Sections 3.2 and 3.3 describe case studies that examine the effects and recovery of aquatic and benthic communities following disturbance events. The majority of the studies document dredging and capping events; however, other events like severe scour and channel relocation are briefly discussed. The studies have been completed to investigate the mechanisms influencing recolonization of benthic invertebrates and fish, although studies of aquatic vegetation, epibenthic invertebrates, plankton, and periphyton have also been completed.

3.2.1 Removal Actions

DEPOSIT N, LOWER FOX RIVER WISCONSIN (FOTH AND VAN DYKE, 2000)

A demonstration removal action of 11,000 cubic yards (cy) was initiated at Deposit N in 1998 and completed in the fall of 1999. Water depths at the location were generally 8 feet deep, with an average sediment thickness prior to removal of 2 to 3 feet (Foth and Van Dyke, 2000). Given that Deposit N lay over bedrock material and the project specification was to dredge to a depth immediately above the bedrock (approximately 6 inches), a marker exists against which to evaluate future sediment accumulation.

Sampling was conducted in July 2002 to determine: (1) the depth of material that had reaccumulated over the bedrock (i.e., original cut), (2) the surface concentrations of PCBs, and (3) the benthic infaunal communities in place 3 years after cessation of dredging.

Throughout Deposit N, there has been very little sediment accumulation. Samples were collected at stations S-5 and S-13, which were previously sampled in 1997 pre-dredging. At S-5 there was a total depth of sediment of approximately 10 inches, but S-13 had courser-grained material closer to the shore wall. Poling conducted through the rest of the site showed that with the exception of the western lobe nearer to S-5, there is very little additional accumulation. Sixty soundings were taken, and on average there is still only approximately 6 inches of sediment over most of the deposit.

SMU 56/57, LOWER FOX RIVER (IPS, 2000A, 2000B, 2000C)

The Sediment Management Unit (SMU) 56/57 demonstration project was conducted over two seasons and completed in the fall of 2000. Approximately 31,000 cy of dredged material was removed from SMU 56/57 in 1999. Grain size and benthic community were investigated the summer prior to dredging and at 3 and 9 months following termination of the 1999 dredging activity. Additional samples were collected in July of 2002. Three samples at water depths prior to dredging to 5 feet, between 5 and 10 feet, and greater than 10 feet from each of two transects were collected for all three surveys. Post-dredging surveys returned to each of these stations and two additional stations were established following dredging. Upon completion of the dredging operations, a sand cap was placed at the bottom of the dredge hole to act as a marker for future sampling.

Pre-dredging grain size distributions for each station at SMU 56/57 are contained in Table 4. Substrate was predominantly silt at four stations and sand at the other two stations. Three months following dredging, substrate changed to silt from sand at one station, but remained similar to pre-dredging distributions. The amount of clay remaining in exposed substrate following dredging increased at each station, but fractions of silt tended to be greater in the 9-month samples. Nine months following dredging, substrate changed to either silty clay or clayey silt. In the July 2002 sampling, a total of 5 feet of sediment had accumulated over the top of the placed sand cap layer. Total PCB concentrations in those samples are not available at this time.

TABLE 4 GRAIN SIZE DISTRIBUTION (PERCENT) AT SMU 56/57

	Transect 1			Transect 2			Transect A	Transect B
	Position 1	Position 2	Position 3	Position 1	Position 2	Position 3		
Water Depth:	0–5 ft	5–10 ft	> 10 ft	0–5 ft	5–10 ft	> 10 ft	5–10 ft	5–10 ft
August 27, 1999								
Sand	72.5	34.6	34.3	75	25.4	35	—	—
Silt	15	49	51.4	12.5	58	50	—	—
Clay	12.5	16.4	14.3	12.5	16.6	15	—	—
Total Fines	27.5	65.4	65.7	25	74.6	65	—	—
Organic Material	14.4	15.4	12.8	18.7	11.9	10.7	—	—
March 6, 2000								
Sand	67.5	27.5	26	37.5	30	27.5	27.5	35
Silt	17.5	40	41.4	37.5	37.5	40	42.5	37.5
Clay	15	32.5	32.5	25	32.5	32.5	30	27.5
Total Fines	32.5	72.5	73.9	62.5	70	72.5	72.5	65
Organic Material	30.3	14.2	14.3	12.6	11.8	12.4	14.4	12.7
August 3, 2000								
Sand	25	30	17.5	30	27.5	27.5	25	27.5
Silt	47.5	30	45	35	35	30	40	40
Clay	27.5	40	37.5	35	37.5	40	35	32.5
Total Fines	75	70	82.5	70	72.5	70	75	72.5
Organic Material	22.4	14.6	14.4	14.3	12.3	15.5	14.5	13.5

Pre- and post-benthic invertebrate abundances for each station at SMU 56/57 are listed in Table 5. Oligochaetes and chironomids dominated benthic samples before and after dredging. Before dredging, abundances averaged 745 organisms/square foot (organisms/ft^2). Oligochaetes and chironomids comprised 84 and 15 percent of the total population, respectively. Three months following dredging, abundances were higher, averaging 1,035 organisms/ft^2, with oligochaetes accounting for 91 percent of the population. Nine months following dredging, abundances were 374 organisms/ft^2, with oligochaetes accounting for 94 percent. Abundances increased in several stations from the 3-month sampling, but were more similar to pre-dredging levels than 3-month levels.

Abundance recovered to greater than pre-dredge levels 3 months following dredging, but likely represented initial opportunistic colonizers that drifted into site post-removal. The sudden increases in oligochaete abundance and relatively stable chironomid abundance following dredging indicate that despite changes from sandy and silty sediment to silty and clayey sediment, recolonization occurred in as little as 3 months with similar diversity. Within 9 months, the species composition and abundances reflected the pre-dredging conditions.

TABLE 5 BENTHIC INVERTEBRATES AT SMU 56/57

	Transect 1			Transect 2			Transect A	Transect B	Average per Station		Percent Group
Water Depth:	**Position 1 0–5 ft**	**Position 2 5–10 ft**	**Position 3 > 10 ft**	**Position 1 0–5 ft**	**Position 2 5–10 ft**	**Position 3 > 10 ft**	**5–10 ft**	**5–10 ft**			
August 27, 1999											
Oligochaeta	1,112	1,368	536	400	166.7	153.3	—	—	622.666667	0.83515894	84
Diptera											
Chironomidae	176	193.3	114	56	60	50.7	—	—	108.333333	0.14530335	15
Amphipoda											
Family Gammaridae	2	0	0	0	0	0	—	—	0.33333333		
Gastropoda											
Family Pleuroceridae	0.7	0	0	8	0	0	—	—	1.45		
Bivalvia	64	0	0	0	0.7	0	—	—	10.7833333		
Nematoda	0	0	8	0	0	2.7	—	—	1.78333333		
Hirudinea	0	0	0	0	1.3	0	—	—	0.21666667		
Total	**1,354.7**	**1,561.3**	**658**	**464**	**228.7**	**206.7**	**—**	**—**	**745.566667**		
March 6, 2000											
Oligochaeta	1,256	132	3,488	984	834	604	34.7	228	945.0875	0.91286342	91
Diptera											
Chironomidae	250	9.3	193	56	119.3	48	16	28	89.95	0.08688303	9
Amphipoda											
Family Gammaridae	0	0	0	0	0	0	0	0	0		
Gastropoda											
Family Pleuroceridae	0	0	0	0	0	0	0	0	0		
Bivalvia	0.7	0	0	0	0	0	0	0	0.0875		
Nematoda	0	0	0	0	0	0	0	0	0		
Hirudinea	0.7	0	0	0	0	0	0	0	0.0875		
Turbellaria	0	0.7	0	0	0	0	0	0	0.0875		
Total	**1,507.4**	**142**	**3,681**	**1,040**	**953.3**	**652**	**50.7**	**256**	**1,035.3**		
August 3, 2000											
Oligochaeta	225.3	688	116	158	332	54.7	482	722.7	347.3375	0.92833757	93
Diptera											
Chironomidae	51.3	42	0.7	8.7	30	0.7	31.3	27.3	24	0.0641454	6
Amphipoda											
Family Gammaridae	0	0	0	1.3	0	0.7	0	0	0.25		
Gastropoda											
Family Pleuroceridae	0	1.3	0	0	0	0	0	0	0.1625		
Bivalvia	0	0	0	0	0	0	0	0	0		
Nematoda	0	0	8	1.3	0	1.3	3.3	4	2.2375		
Hirudinea	0	0	0	0	0	0	0	0	0		
Nematomorpha	0	0	0	0	0	0	1.3	0	0.1625		
Horsehair, Gordian worms	276.6	731.3	124.7	169.3	362	57.4	517.9	754	374.15		

WISCONSIN SPRING PONDS (CARLINE AND BRYNILDSON, 1977)

Two spring-fed ponds, Krause and Sunshine Springs, were dredged with a hydraulic dredge to remove organic sediments and restore or enhance sport fisheries for brook trout (*Salvelinus fontinalis*) by increasing water depth and removing aquatic macrophytes. The pond was studied for 2 years before dredging and 4 to 5 years afterwards (1967–1975). The ponds were 0.3 and 0.4 hectares in surface area. Prior to dredging, beds of *Chara*, also known as skunkweed, an invasive type of SAV, covered nearly 60 percent of the pond bottom. Densities of major benthic taxa before and after dredging are shown in Table 6. Chironomids were the dominant organisms and oligochaetes accounted for about 4 percent of all organisms.

TABLE 6 COMPARISONS OF MEAN ANNUAL DENSITIES OF MAJOR BENTHIC TAXA BEFORE AND AFTER DREDGING IN TWO WISCONSIN SPRING PONDS

Taxa	Krause Springs				Sunshine Springs			
	1968–69		1975		1968–69		1975	
	Means (org./m^2)	%	Means (org./m^2)	%	Means (org./m^2)	%	Means (org./m^2)	%
Oligochaeta	54	4.2	2,460	70.1	53	4	3,503	56
Hirudinea	2.9	0.4	0.05	< 0.06	2.4	0.4	0.6	0.1
Gastropoda	1	0.1	0.6	0.2	5.2	0.8	2	0.3
Gammarus	46	6	14	5	6.2	3.2	68	10.2
Hyalella	91	38	0.1	< 0.06	2	< 0.06	0	0
Chironomidae	1,825	49.8	716	20.6	4,113	91.2	2,230	31.8
Total	**4,557**	**100**	**6,826**	**100**	**4,972**	**100**	**14,758**	**100**

After dredging, marl substrates predominated and areas of exposed mineral soils increased, providing approximately 1 additional meter of water depth in each pond. Water temperature and concentrations of dissolved materials did not change significantly. Dredging completely eliminated aquatic macrophytes and plant recolonization proceeded slowly. Recolonization first became evident about 1 year after dredging. In Sunshine Springs, biomass of *Chara* reached about 10 percent of pre-dredging levels after 5 years.

Densities of benthic organisms were severely reduced in the short-term by dredging, but recolonization was rapid. Oligochaetes recolonized rapidly and became the most numerous taxa and 4 to 5 years after dredging; they comprised 56 to 70 percent of all benthic organisms. Combined densities of all benthic taxa in Krause Springs was 50 percent higher than pre-dredging values and those in Sunshine Springs were nearly three times as great as pre-dredging densities, largely due to increased oligochaetes. Densities of the cladocerans *Daphnia* and *Bosmina* increased after dredging and the amphipod *Gammarus* reached pre-dredging levels within 5 years. The density of chironomids was reduced by 61 and 46 percent after dredging in Krause and Sunshine Springs, respectively. Leeches, *Hyalella*, and sialids were common in organic sediment, but decreased significantly following dredging. Zooplankton density was too low to allow detection before dredging and increased within 1.5 years, dominated by large populations of *Daphnia ambigua* and *Bosmina coregoni*.

Fish communities were temporarily altered by dredging. When benthic organisms, the primary food of trout, experienced decreased densities due to dredging, the growth rates of trout declined. As benthic communities recolonized, trout growth rates also increased. In shallow ponds, trout densities fluctuated greatly because of large-scale emigrations and immigrations. After dredging, emigrations were much reduced. The standing crop of brook trout in Krause Springs changed little after dredging, because numbers of trout hatched in the pond annually did not appreciably increase. Conversely, at Sunshine Springs, there was a marked increase in recruitment, and 5 years after dredging trout biomass was nearly triple that of pre-dredging levels. Brown trout (*Salmo trutta*), all of which were emigrants, accounted for more than half of the biomass increase.

Aquatic vegetation did not recover; however, the purpose of the dredging was to remove organic sediment and increase water depth to levels that would prevent the growth of invasive aquatic vegetation and development of filamentous algae mats. Accumulation of organic matter from allochthonous sources and native aquatic vegetation will likely enhance benthic productivity of the predominantly marl substrates.

RIVER HULL, ENGLAND (PEARSON, 1984)

The effects of dredging were studied on the River Hull in England. The River Hull is a lowland stream with average discharges of up to 700 cubic feet per second (cfs) during flooding. Invertebrate populations were measured monthly at one station (Station 24) 17 months before dredging until 5 months after dredging, and at another station (Station 22) from 5 months before dredging to 17 months after dredging. Deposition of fine sediments increased during periods of low flow but was washed out during high winter flows. Several key metrics used to characterize the benthic community for the period before and after dredging at each of the dredged stations are shown in Table 7.

At Station 24, current velocity and the distribution of substratum were not greatly affected by dredging, despite substratum removal. Macrophytes were not present throughout the sampling period. The amphipod *Gammarus pulex* was the most abundant species, and oligochaetes were the next most abundant at Station 24 before and after dredging. In the 5 months following dredging in December 1972, the prevalence of the snail *Potamopyrgus jenkinsi* increased in frequency of occurrence and abundance. Mayflies were also more popular following dredging, and Shannon diversity, number of taxa, and biomass were similar to pre-dredging levels only several months following dredging. Total abundance in 1973 appeared to be similar to pre-dredge levels in the same months of 1972.

TABLE 7 RIVER HULL SEDIMENT INVERTEBRATE METRICS BEFORE AND AFTER DREDGING

		Station 24				Station 22			
		Abundance	Biomass	Number of Taxa	Shannon-Weaver Index	Abundance	Biomass	Number of Taxa	Shannon-Weaver Index
1971	June	NS				495	3.4	18	3.4
	July	661	1.8	9	1.3	475	4	18	3.3
	August	765	2.3	10	0.8	760	6.9	19	3.8
	September	2,216	7.5	9	0.3	1,471	15.9	28	3.7
	October	1,502	3.6	7	0.3	1,662	17.5	23	3.6
	November	2,545	8.2	7	0.3	2,940	24.1	25	3.3
	December	2,010	8.1	6	1.2	NS			
1972	January	1,566	7	7	0.8	**845**	**10.5**	**12**	**2.6**
	February	751	6.5	14	1.8	**677**	**10.1**	**17**	**3.1**
	March	477	5.1	7	1.5	**428**	**8.4**	**16**	**2.8**
	April	489	5.1	8	1.7	**207**	**5.9**	**16**	**3.4**
	May	1,133	8.3	11	1.7	**147**	**1.2**	**12**	**2.7**
	June	4,345	8.2	16	1.8	**234**	**2.2**	**17**	**2.3**
	July	3,285	12.7	12	0.8	**147**	**1**	**20**	**3.7**
	August	2,633	6.9	22	2.3	**575**	**4.2**	**25**	**3.2**
	September	3,567	7.1	16	1.1	**852**	**7.4**	**25**	**3.2**
	October	1,309	4.7	14	1.2	**705**	**6.8**	**22**	**2.9**
	November	1,988	2.1	11	1.6	**404**	**2.6**	**17**	**2.8**
	December	1,436	2.6	8	1.4	**314**	**3.2**	**15**	**2.3**
1973	January	**675**	**2.4**	**12**	**0.7**	449	4.3	20	3.1
	February	**549**	**1.8**	**10**	**0.8**	463	3	22	3.4
	March	**762**	**2.3**	**14**	**0.9**	519	5.9	19	3.3
	April	**842**	**6.7**	**7**	**0.6**	298	6.8	20	3.5
	May	**923**	**9.5**	**13**	**0.9**	275	3.6	20	3

Notes:
Bold – Indices Following Dredging
NS – Not Sampled

Dredging at Station 22 caused marked drops in current velocity following the removal of substratum and most of the plants. The new substrate consisted of soft silt and plant fragments overlying a clay/gravel bed. The aquatic macrophyte *Elodea canadensis* and green algae *Cladophora* spp. became dominant following dredging at Station 22. Before dredging, oligochaetes, leeches, gastropods, and chironomids were dominant. Chironomids were present in similar densities before and after dredging, but densities of oligochaetes and some gastropods declined quickly following dredging. The caddisfly *Hydroporus* spp., which was one of the more populous organisms before dredging became the dominant organism afterwards. The number of taxa and Shannon diversity showed a fairly quick recovery following dredging.

At both stations, the number of taxa of benthic invertebrates had recovered in 6 months but abundance and community composition had not returned to pre-disturbance conditions after 1 year. Fauna of the faster flowing, more lotic segment (Station 24) appeared to be better able to withstand mechanical disturbance (current and turbulence) and to repopulate than fauna of the more lentic segment (Station 22).

BRYANT MILL POND DREDGING PROJECT – WISCONSIN (EPA Region 6 Communication)

Allied Paper, Inc. widened a stream channel flowing from Bryant Mill Pond by dredging and regrading the areas adjacent to the stream channel. Remediation was completed in March 1999 without any habitat enhancement. Figures 3 and 4 are pictures just following remediation, and Figures 5 and 6 are pictures 4 months following remediation of each of the locations shown on Figures 3 and 4, respectively. Wetland and aquatic vegetation has obviously established following remediation in areas disturbed by dredging or regrading.

Figure 3 Lower Stream Reach Following Remediation, March 1999

Figure 4 Upper Stream Reach Following Remediation, March 1999

Figure 5 Lower Stream Reach Following Remediation, August 1999

Figure 6 Upper Stream Reach Following Remediation, August 1999

COLLINGWOOD HARBOUR – ONTARIO, CANADA (ENVIRONMENT CANADA, 1998)

Sediment in Collingwood Harbour was contaminated with metals from historical shipbuilding activities. Dredging was performed as part of navigation maintenance in the harbor in 1986, a pilot remedial dredging project in 1992, and as the cleanup remedy in 1993 that resulted on the removal of 2.45 acres. Sediments consisted of soft silt overlying clay and bedrock.

Benthic invertebrate identification was conducted in 1992 and 1993 throughout the harbor to determine baseline conditions. Oligochaetes were found to be abundant in areas of low-level toxicity as shown in the analysis of the benthic community structure. Following dredging, benthic community structure and biomass resembled control sites of comparable physical and chemical characteristics.

3.3 ENVIRONMENTAL EFFECTS OF CAPPING ON BIOTA, FISH, AND SAV

There are no capping projects with demonstrated long-term monitoring or effectiveness that exist in any riverine system anywhere in the world. Thus, evaluating the short- and long-term environmental effects of capping can only be estimated from projects done in marine or lake environments. The FS listed a number of capping projects that have been conducted around the world. Despite the fact that a number of caps have been built, only two projects collected specific post-placement environmental effects information. These are discussed below.

SIMPSON CAPPING PROJECT – TACOMA, WASHINGTON (STIVERS AND SULLIVAN, 1994)

The St. Paul Waterway Area Remedial Action and Habitat Restoration Project was one of the first aquatic Superfund remediations in the country. The previously contaminated site was capped and intertidal habitat was designed for the cap surface to encourage recolonization by benthic infauna and macrophytes (algae), and use by fish and birds. Physical and biological monitoring was performed for 5 years following cap placement.

A sand cap with a thickness of 2.5 to 6.5 meters was placed over the 17-acre area in 1987 and 1988. Benthic invertebrate abundance and complexity monitored annually from 1988 to 1993 have shown an overall increase. Immediately after construction, the area was essentially new, uncolonized habitat. The total abundance of benthic organisms increased steadily through 1992. In 1993, there was a slight decrease in the total abundance measured at the site; however, the overall trend has been one of increasing benthic abundance from essentially zero in 1988 to a range of 1,172 to 9,718 organisms per station in 1993. Following remediation, benthic invertebrate community abundance and diversity observed at the project site have been comparable to those found at various reference sites tested, indicating that the community resembles a typical healthy back-bay mudflat in Puget Sound.

Epibenthic populations and variability since cap construction has been similar to the ranges and variability found at various reference sites tested during the 5 years of monitoring. Macrophyte coverage at the site has increased greatly since construction, appearing to achieve the maximum possible coverage given the availability of hard surfaces for macrophyte attachment at the site.

SODA LAKE, WYOMING (THERMORETEC, 2001)

A demonstration cap was placed over refinery residuals in a settling pond located near Casper, Wyoming. A pilot capping project was conducted, placing 3 feet of clean sand over the highly plastic process residuals. Benthic invertebrates were collected prior to cap placement from ten stations in March 2000 and 11 months following cap placement (June 2001) from the same ten stations, four of which were located on the cap.

Benthic infauna appeared to be relatively tolerant of the organic pollution present in the Inlet Basin sediment. Chironomids accounted for approximately 42 percent of the total benthic invertebrate population in the organic sediments. The remainder was composed mostly of gastropods and *Hyalella azteca*. Oligochaetes were also identified prior to capping but in fewer numbers than chironomids, gastropods, and *Hyalella*. Twenty-eight different organisms were identified in Inlet Basin sediment, with the total taxa per station averaging nine. The number of taxa ranged from fourteen (two stations) to three (two stations). Shannon-Weaver diversity (H') was estimated for each station and for the group average; higher indices indicate greater diversity. The average diversity (H') was 2.15 for the Inlet Basin; diversity indices ranged from 1.10 to 2.94.

Following capping, chironomids and oligochaetes accounted for approximately 32 and 58 percent of the total benthic population, respectively. Table 8 contains results of cap stations and non-cap stations 11 months following cap placement. Chironomids were approximately twice as abundant and oligochaetes were greater than six times as abundant at cap stations than off-cap stations 11 months following cap placement. Shannon diversity was lower at both cap and off-cap stations than the baseline investigation, averaging 0.32 and 0.17, respectively. Prior to cap placement, oligochaetes were present at only five of the ten stations sampled, but dominated following cap placement.

Seasonal differences in benthic population are likely present; however, comparisons of cap stations to off-cap stations may be made. The substrate change from silt and clay to sand and the absence of organic content are likely the cause of the decline in diversity.

3.3.1 Other Disturbances

CHANNELIZATION

Channelization greatly degrades and simplifies in-stream habitat by eliminating channel river meanders and riparian vegetation and removing snags and in-stream and streamside vegetation. Long, uninterrupted stretches of uniform habitat are developed by unifying stream gradient and removing complexities in rivers, likely reducing the abundance and species richness of the colonizing invertebrate communities (Hortle and Lake, 1982).

Effective habitat mitigation strategies have decreased siltation and increased pool volume, allowing recovery to occur within 5 years (Hunt, 1976; Edwards et al., 1984). In general, recovery in channelized systems has been mediated by organism-specific food requirements and habitat preferences. In the Olentangy River, Ohio, productive backwater refugia ensures the continued presence of bottom-dwelling detritus feeders (carp) and species such a channel catfish (Arner et al., 1976; Edwards et al., 1984). In the Luxapalila River in Mississippi, fish populations are still not considered recovered after 52 years (Arner et al., 1976).

Many channelization projects eliminate nearby source areas for recolonization, causing recovery and recolonization to be long-term. Milner (1987) determined that in 25-year-old glacial stream invertebrate communities still have not achieved maximum diversities despite achieving maximum densities 14 years earlier. This study illustrates that colonization (and hence recovery) is a long-term process when there are no upstream source areas for drift and refugia areas are distant.

FLOODS

Floods are rarely of sufficient magnitude to remove the entire stream biota (Minshall et al., 1983). Nevertheless, floods disturb community structure and function, sometimes forcing recovery times to be long, especially when floods are uncommon in the area. Frequent floods disrupt the established algal community, often favoring well-resistant taxa (Milner, 1994). In a small Irish river, a flood reduced macroinvertebrate densities to less than 5 percent of pre-flood levels (Giller et al., 1991). Recovery was less than 50 percent of the original density after 2 years; however, there was no apparent effect on the resident salmonid populations.

TABLE 8 BENTHIC INVERTEBRATE COUNTS 11 MONTHS FOLLOWING CAP PLACEMENT ON THE INLET BASIN – SODA LAKE

Taxa	SLIB-01	SLIB-02	SLIB-03	SLIB-04	Cap Average	SLIB-5	SLIB-06	SLIB-07	SLIB-8	SLIB-9	SLIB-10	Non-cap Average
Insecta												
Ephemeroptera												
Caenis sp.	1	0	3	0	1	0	3	0	1	0	0	1
Trichoptera												
Lepidostoma sp.	1	0	0	0	0	0	0	0	0	0	0	0
Odonata												
Coenagrionidae	0	0	0	0	0	0	2	0	0	0	0	0
Diptera												
Chironomidae	63	17	108	1	47	3	82	1	39	20	1	24
Annelida												
Oligochaeta												
Unid. Oligochaeta	154	32	139	7	83	1	1	0	65	4	1	12
Nematoda												
Unid. Nematoda	29	4	4	0	10	0	0	0	2	1	0	1
Crustacea												
Amphipoda												
Hyalella sp.	1	0	3	0	1	0	5	0	0	0	0	1
Mollusca												
Gastropoda	0	0	4	0	1	0	4	0	7	1	0	2
Fossaria sp.	0	0	0	0	0	0	1	0	0	0	0	0
Lymnaeidae	0	0	3	0	1	0	0	0	1	0	0	0
Physella sp.	0	0	0	0	0	0	0	0	0	1	0	0
Physidae	0	0	1	0	0	0	3	0	4	0	0	1
Planorbidae	0	0	0	0	0	0	0	0	1	0	0	0
Neotaenioglossa												
Hydrobiidae	1	0	0	0	0	0	0	0	0	0	0	0
Total (organisms/m^2)	**11,101**	**2,391**	**11,618**	**369**	**6,370**	**207**	**4,310**	**44**	**5,078**	**1,137**	**74**	**1,808**
Number of Taxa	7	3	7	2	6	2	7	1	7	4	2	6
Shannon-Weaver H'	0.22	0.15	0.20	0.00	0.14	0.00	0.45	0.00	0.32	0.50	0.00	0.21
Evenness	0.26	0.32	0.24	0.00	0.20	0.00	0.53	0.00	0.38	0.83	0.00	0.29

Other studies indicate that fish are usually able to quickly recover from catastrophic flooding. Rainbow trout recolonized a 1-mile stretch of a California river within 4 years following the complete elimination of the resident population (Lambert, 1988). Matthews (1986) reported fish communities to have recovered in 8 months following a catastrophic flood in an Arkansas stream.

NEW STREAM CHANNELS

Newly constructed stream channels and relocated stream channels often are completely without any invertebrate or algal populations. The time to recovery is fairly quick if nearby colonization sources are available. The number of taxa colonizing reached an equilibrium after approximately 100 days in a new, constructed Canadian stream channel (Williams and Hynes, 1976) and a restored stream channel damaged by coal surface mining (Gore, 1979). Although reduced recruitment of new species was observed after approximately 200 days following construction of a new stream in Sweden, chironomids were found first in newly emergent glacial streams (Malmqvist et al., 1991), which was similar to colonization of glacial streams of different age (Milner, 1987).

4 POTENTIAL IMPACTS OF REMEDIAL ACTIONS

This section discusses the potential for adverse effects and recovery following either of the two potential remedies (dredging or capping) proposed for the Lower Fox River. It addresses the issue that removal or burial of sediment adversely and permanently affects the benthic invertebrates and fish population currently inhabiting the River. Additionally, the occurrence of SAV is assessed to better determine the actual impact of the proposed dredging footprint to 1 ppm total PCBs.

4.1 POTENTIAL FOR RECOVERY FOLLOWING REMEDIAL ACTION

This section estimates the effect of dredging or capping on each habitat and how these changes may affect the food web of the Lower Fox River.

4.1.1 Habitat

Important habitats crucial to maintaining the fish population in the Lower Fox River are fast-flowing areas with hard substrate, including sand, gravel, and cobble habitat, and shallower, slower flowing areas that have soft sediment and provide shelter in the form of submerged and emergent aquatic vegetation. These habitats are further discussed to better understand the effects on fish from dredging. The majority of the substrate targeted for dredging is composed of soft sediments. Fish migrating away from dredging activities will need to find suitable habitat where they may successfully feed and spawn.

HARD SUBSTRATE

Areas targeted for dredging or capping in the Lower Fox River are predominantly soft, aqueous, and silty sediments. Many fishes in the Lower Fox River utilize open substrate like rock with high dissolved oxygen for spawning and adult habitat. These areas are not targeted for dredging. Fish utilizing rock substrate with fast-flowing water include common and emerald shiners, walleye, and rainbow smelt. The presence of riprap on riverbanks provides additional spawning habitat in each OU for walleye and other fish that require rocky substrate for spawning. Much of the fast flowing, rocky substrate in the Lower Fox River is located in OU 2. This area and riffles created by dams in OUs 3 and 4 (none of which are targeted for dredging) will remain unimpacted and be important for fish requiring this type of habitat.

Historical walleye spawning enhancement projects and walleye stocking programs have been successfully undertaken in the Lower Fox River by the Wisconsin Department of Natural Resources and City of De Pere, Wisconsin. New spawning habitat was created at two locations in the Lower Fox River and spawning habitat was enhanced at another location by increasing desirable substrate adjacent to a good quality, highly used spawning area (Lychwick, 1995). Substantial increases in fingerling walleye and egg survival appear to have occurred with the best success at Voyageur Park, where egg deposition was estimated at 5.2 million eggs (Lychwick, 1995). Although these areas are to be left undisturbed as part of the Proposed Plan, they do demonstrate the potential success of similar management programs following disturbance, if necessary.

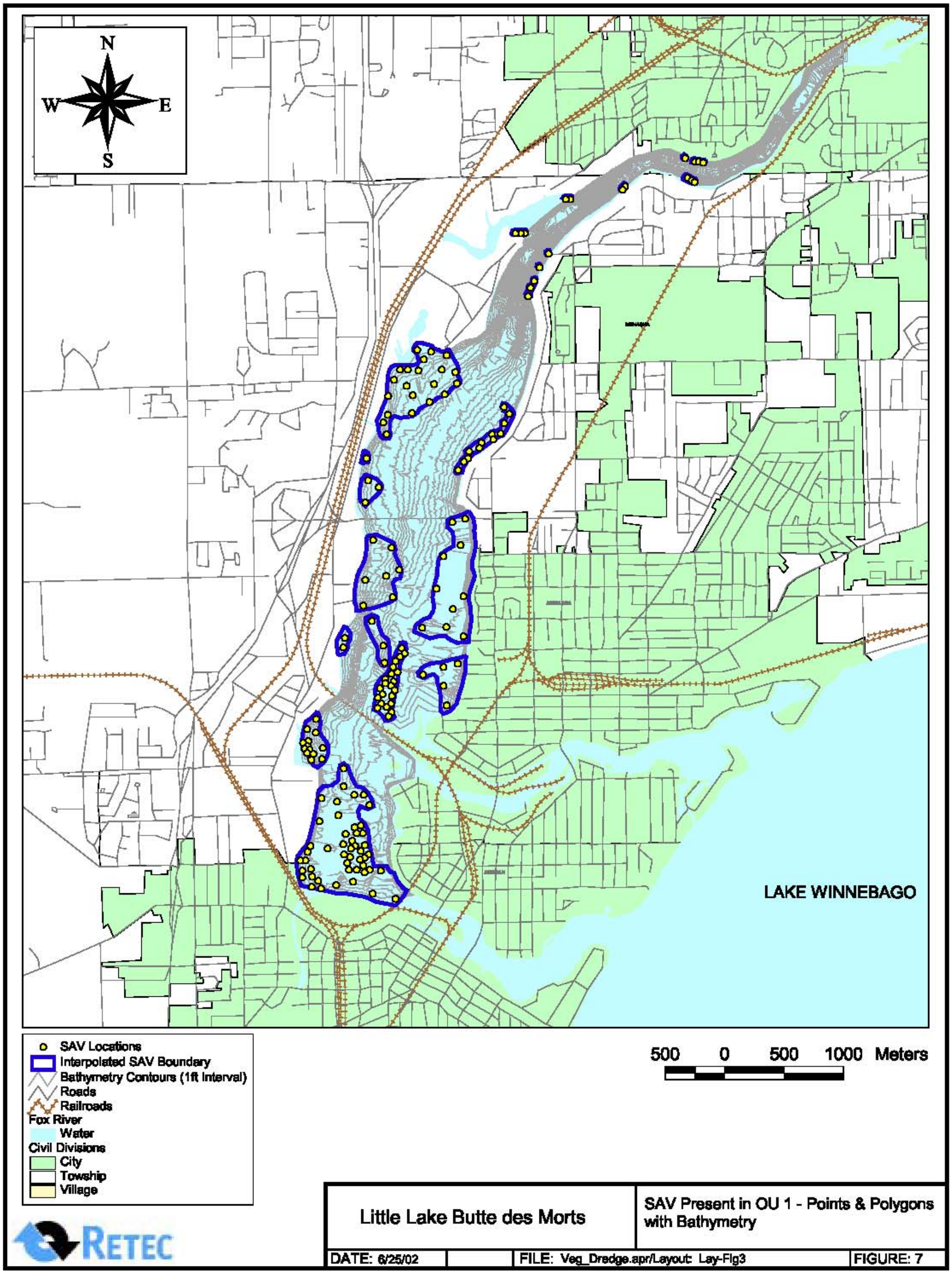
SAV

SAV and emergent aquatic vegetation are likely to grow in the soft, aqueous, and silty sediments, some of which is proposed for dredging or capping. SAV is an important habitat that supports many of the resident fish species in the Lower Fox River. Macrophytes provide shelter and oviposition sites for benthic invertebrates, and substrata for epiphytic algae and invertebrates (Harrod, 1964; Westlake, 1975; Cattaneo and Kalff, 1980). Vegetation provides food in the form of epiphytic algae, decaying plant material, and fine particulate organic matter that accumulates in plant beds (Kaenel et al., 1998). Juvenile fish are also able to utilize the vegetated areas as nursery habitat because of slower flows and shelter from predators (Aldridge, 2000). Golden shiners, carp, and yellow perch require aquatic vegetation at some point for spawning or adult habitat. Other juvenile fish use the vegetated areas as shelter and protection from predators.

The fish present in the Lower Fox River are mobile species that seek out appropriate spawning habitat. Many naturally occurring backwater areas are present in Little Lake Butte des Morts as well as other artificial backwater areas resulting from dams in the Lower Fox River. These areas, along with tributaries entering along the entire River, are valuable backwater habitat that provide sources from which migration may occur and shelter during disturbances like dredging. Submerged and emergent aquatic vegetation is key for providing shelter in these areas. Studies have shown the benefit of natural refugia in the form of off-channel brood ponds as an important factor in speeding recovery of disturbed rivers and streams (Detenbeck et al., 1992).

SAV is most prevalent in Little Lake Butte des Morts (OU 1), and present in backwater areas in OUs 3 and 4. Little Lake Butte des Morts contains slower velocities, shallower water depths, and more fluctuating water levels than OUs 3 and 4. Figure 7 shows SAV distribution in Little Lake Butte des Morts in relation to 1-foot bathymetric contour intervals. Also contained on this figure are polygons created by Exponent to group each of the SAV locations identified in the survey.

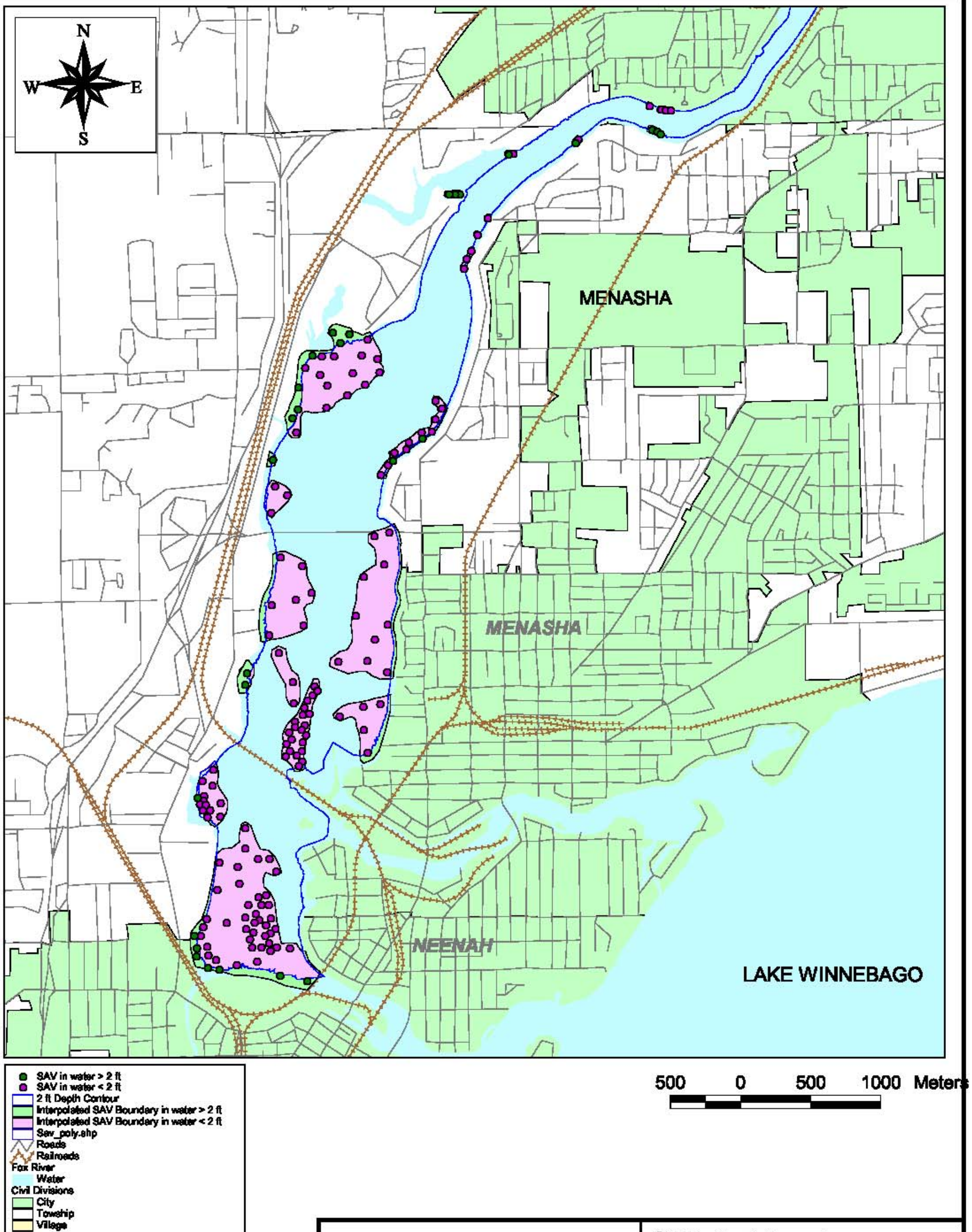
Exponent (1999) estimated that 60 percent of the shoreline of OU 1 contains SAV. Blasland, Bouck and Lee (BBL) cited the investigation conducted by Exponent (1999) to state that 48 percent of OU 1 is covered with SAV. However, it is likely that many of their estimates are inflated because of the inaccurate assumption that blooms of filamentous green algae that are “associated with SAV” actually indicate the presence of SAV. Filamentous green algae is widespread in Little Lake Butte des Morts, often drifting from Lake Winnebago during southerly winds in sizable portions. Several of the photos provided by Exponent and described as SAV indeed are nothing more than filamentous green algal blooms.


N
W
E
S
LAKE WINNEBAGO
SAV Locations
Interpolated SAV Boundary
Bathymetry Contours (1ft Interval)
Roads
Railroads
Fox River
Water
Civil Divisions
City
Towship
Village
500 0 500 1000 Meters
RETEC
Little Lake Butte des Morts
SAV Present in OU 1 - Points & Polygons with Bathymetry
DATE: 6/25/02
FILE: Veg_Dredge.apr/Layout: Lay-Fig3
FIGURE: 7

Additionally, the suspended sediments of Little Lake Butte des Morts reduces light penetration to such a degree that many species of SAV are unlikely to establish in water deeper than about 2 feet. Turbidity, a measure of suspended particles in water, has been recorded at greater than 100 mg/L before the beginning of the pilot dredging projects (RETEC, 2002b), limiting the depth to which aquatic vegetation could develop.

Figure 8 shows the distribution of SAV above and below the 2-foot bathymetric contour for Little Lake Butte des Morts. As shown on the figure, SAV is present in areas shallower than approximately 2 feet, but was also judged to be present in water deeper than 2 feet in many parts of Little Lake Butte des Morts. Because SAV presence is identified by observations made at single locations, it is unacceptable to infer that SAV is present consistently between each point. Polygons that group SAV locations are shown on Figure 7.

Calculations were performed using a Geographic Information System (GIS) to estimate the total area of SAV in Little Lake Butte des Morts using these polygons. These results are contained in Table 9. Approximately 29.9 percent, or 1,726,800 square meters (m^2), of Little Lake Butte des Morts is covered by SAV as surveyed by Exponent (1999). It is likely this is an overestimate of the coverage of SAV due to Exponent's assumptions regarding the presence of filamentous green algae as indicating SAV presence.



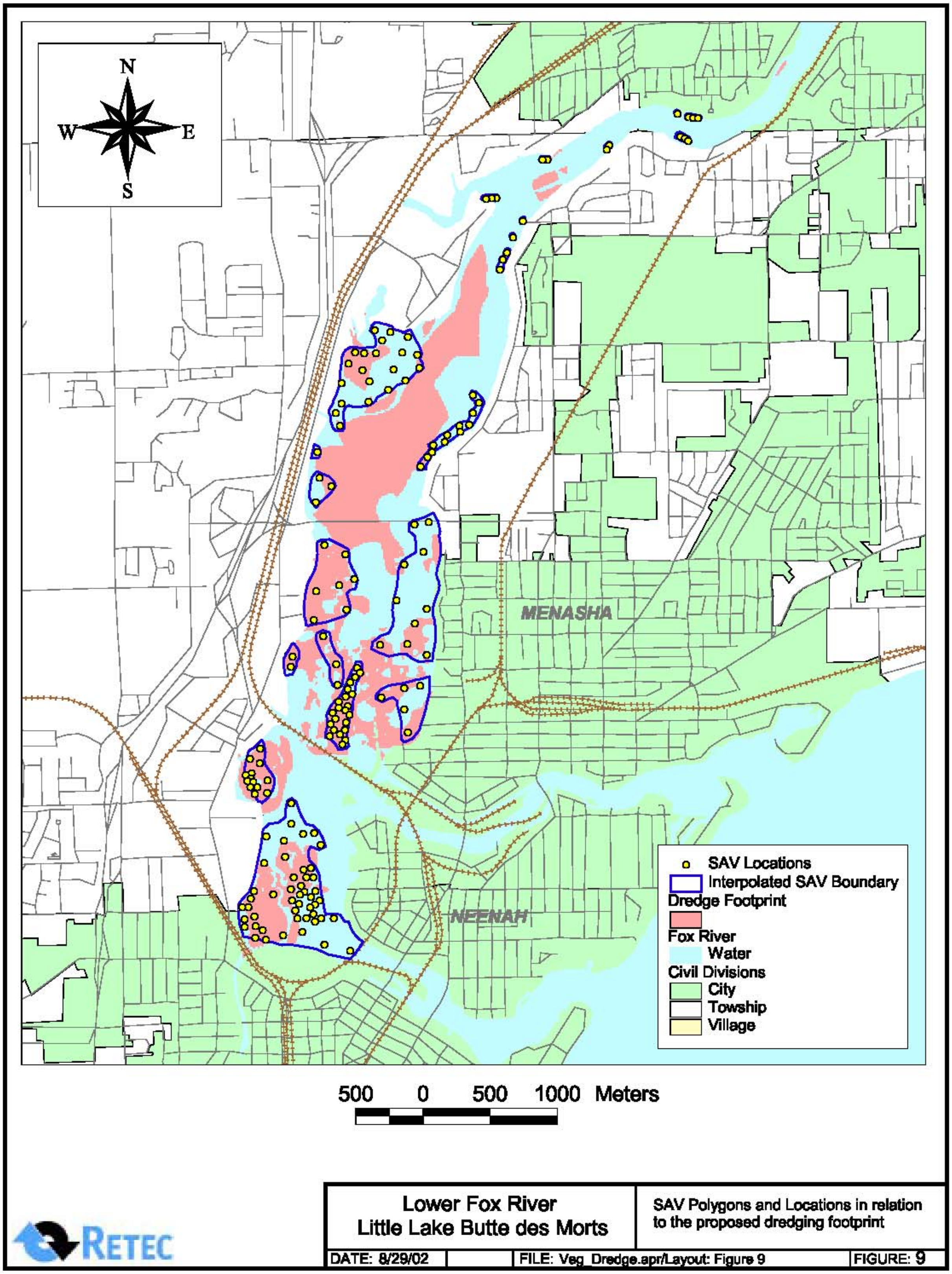
Little Lake Butte des Morts	SAV with Bathymetry @ the 2ft Contour in OU1
DATE: 6/25/02	FILE: Veg_Dredge.apr/Layout: Lay-Fig4 — FIGURE: 8

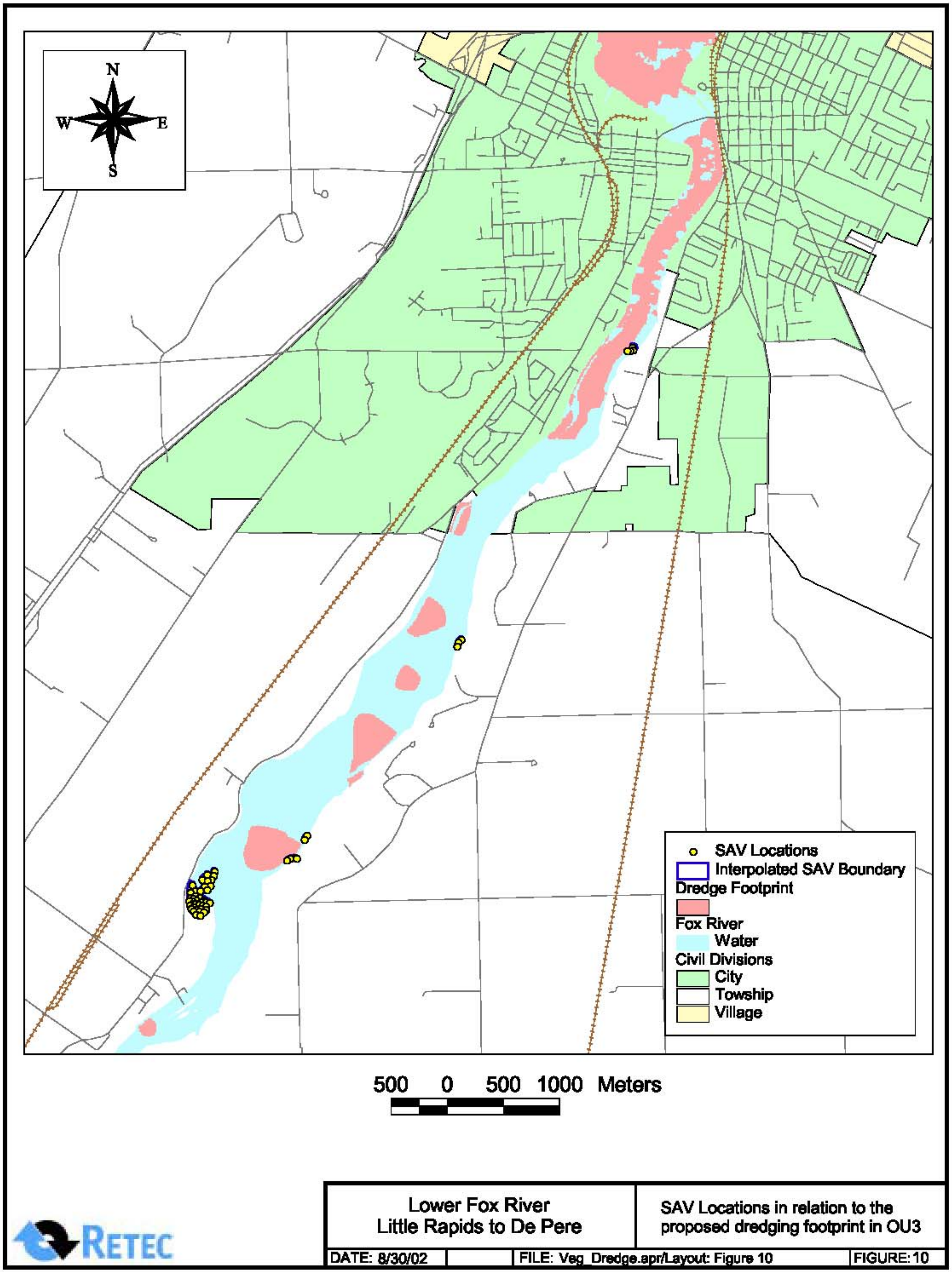
TABLE 9 AREA OF SUBMERGED AQUATIC VEGETATION AND DREDGING

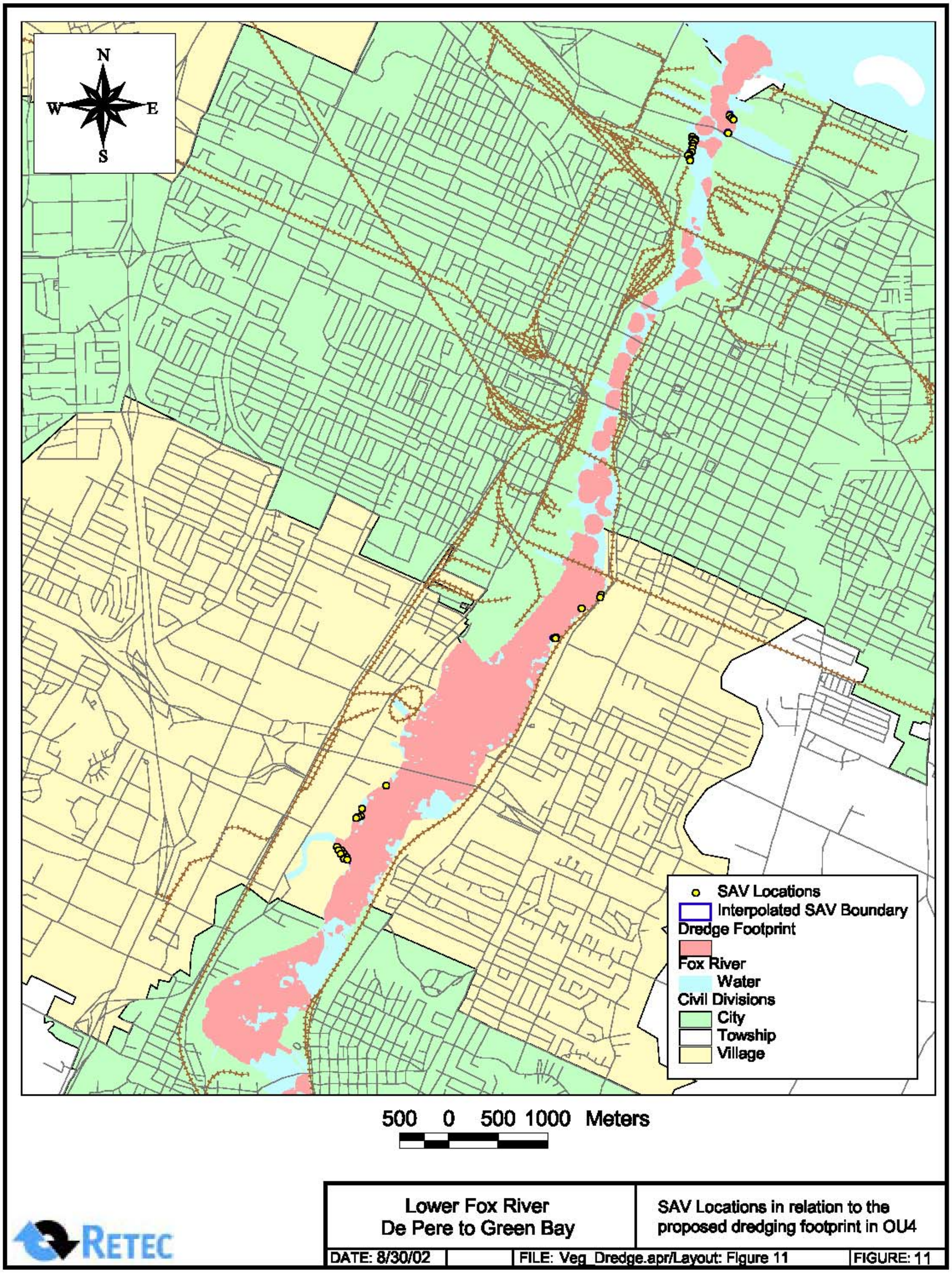
	Total Area (m^2)	Percent Coverage
Submerged Aquatic Vegetation		
Little Lake Butte des Morts		
Total Area of Little Lake Butte des Morts	5,772,171	—
Total Area of SAV in Little Lake Butte des Morts	1,726,800	29.9%
Total area of SAV in < 2 feet water depth	238,900	4.1%
Calculation by Interpolated Polygons		
Total area of SAV inside dredge footprint	734,400	42.5%
Total area of SAV outside dredge footprint	992,400	57.5%
Interpolation by Vegetation Presence/Absence		
Total SAV Points in Little Lake Butte des Morts	376	—
Total SAV points inside dredge footprint	109	29.0%
Total SAV points outside dredge footprint	267	71.0%
Dredging		
Estimated Dredged Footprint		
OU 1	2,130,900	—
OU 2	995,300	—
OU 3	4,071,100	—
Estimated Area Where Firm Subsurface Sediment Will Become Exposed		
OU 1	390,000	18.3%
OU 3	139,300	14.0%
OU 4	1,283,700	31.5%

Estimates were also made to determine the portion of SAV anticipated to be dredged at the 1 ppm total PCB contour. Figure 9 shows the SAV polygons and locations in relation to the dredging footprint (RETEC, 2002b). As shown in Table 9, approximately 42.5 percent of the SAV present in Little Lake Butte des Morts will be dredged. Because the estimates of SAV predicted to be dredged are likely high, an additional analysis of the total number of locations where SAV was identified inside and outside of the dredge footprint was performed. As shown in Table 9, approximately 29 percent of the SAV locations identified during the Exponent survey are located inside the planned dredge footprint. The remainder will remain intact and undredged.

This is a substantial portion of SAV to remain unaffected by dredging. Much of the SAV currently present in Little Lake Butte des Morts is located in nearshore areas that are not targeted for dredging. SAV present in OUs 3 and 4 is estimated to be less than 2 and 3 percent shoreline coverage, respectively (Exponent, 1999). Figures 10 and 11 show SAV locations in relation to the proposed dredging footprints in OUs 3 and 4, respectively. Less than 1 percent of the dredge footprint of both OUs 3 and 4 will affect SAV.


N
W
E
S
MENASHA
NEENAH
SAV Locations
Interpolated SAV Boundary
Dredge Footprint
Fox River
Water
Civil Divisions
City
Towship
Village
500 0 500 1000 Meters
RETEC
Lower Fox River
Little Lake Butte des Morts
SAV Polygons and Locations in relation to the proposed dredging footprint
DATE: 8/29/02
FILE: Veg_Dredge.apr/Layout: Figure 9
FIGURE: 9


N
W
E
S
SAV Locations
Interpolated SAV Boundary
Dredge Footprint
Fox River
Water
Civil Divisions
City
Towship
Village
500 0 500 1000 Meters
Lower Fox River
Little Rapids to De Pere
SAV Locations in relation to the proposed dredging footprint in OU3
DATE: 8/30/02
FILE: Veg_Dredge.apr/Layout: Figure 10
FIGURE: 10
RETEC


N
W
E
S
SAV Locations
Interpolated SAV Boundary
Dredge Footprint
Fox River
Water
Civil Divisions
City
Towship
Village
500 0 500 1000 Meters
RETEC
Lower Fox River
De Pere to Green Bay
SAV Locations in relation to the proposed dredging footprint in OU4
DATE: 8/30/02
FILE: Veg_Dredge.apr/Layout: Figure 11
FIGURE: 11

Although some vegetation will be dredged in Little Lake Butte des Morts, it is not anticipated that flow patterns will change. Slower flows, along with sources for reestablishment provided by nearby, undredged aquatic macrophyte beds support the potential for growth of additional submerged aquatic macrophytes. Waters flowing from Lake Winnebago supply consistent sources for seeds and nutrients that settle and stick in the organic sediment. Slower flow velocities through Little Lake Butte des Morts also provide substantial opportunity for seeds to settle into dredged and undredged sediments. Additionally, these macrophytes die back each winter. They reestablish in the spring either from rhizomes and existing root systems or by way of new seeds buried in the sediment.

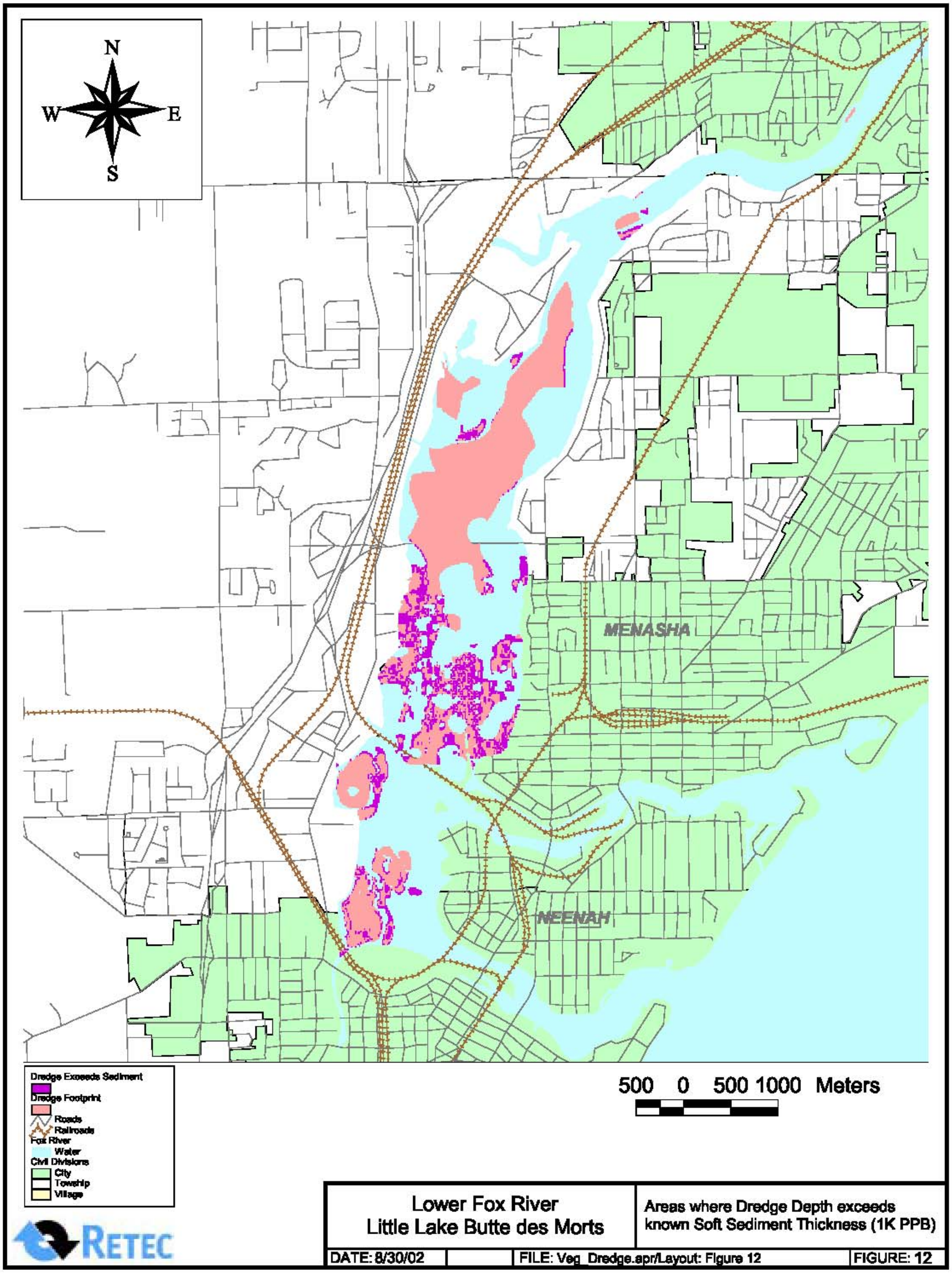
Dredging will increase water depth in some places, potentially preventing aquatic macrophytes from rooting where they were formerly present due to severe light attenuation, but more submerged habitat will be created in the shallower areas to counteract any losses in potential vegetation habitat due to deepening. However, dredged excavations tend to be filled with sediment during high flows (Harvey and Lisle, 1998), which will potentially reclaim former submerged vegetation habitat lost due to dredging.

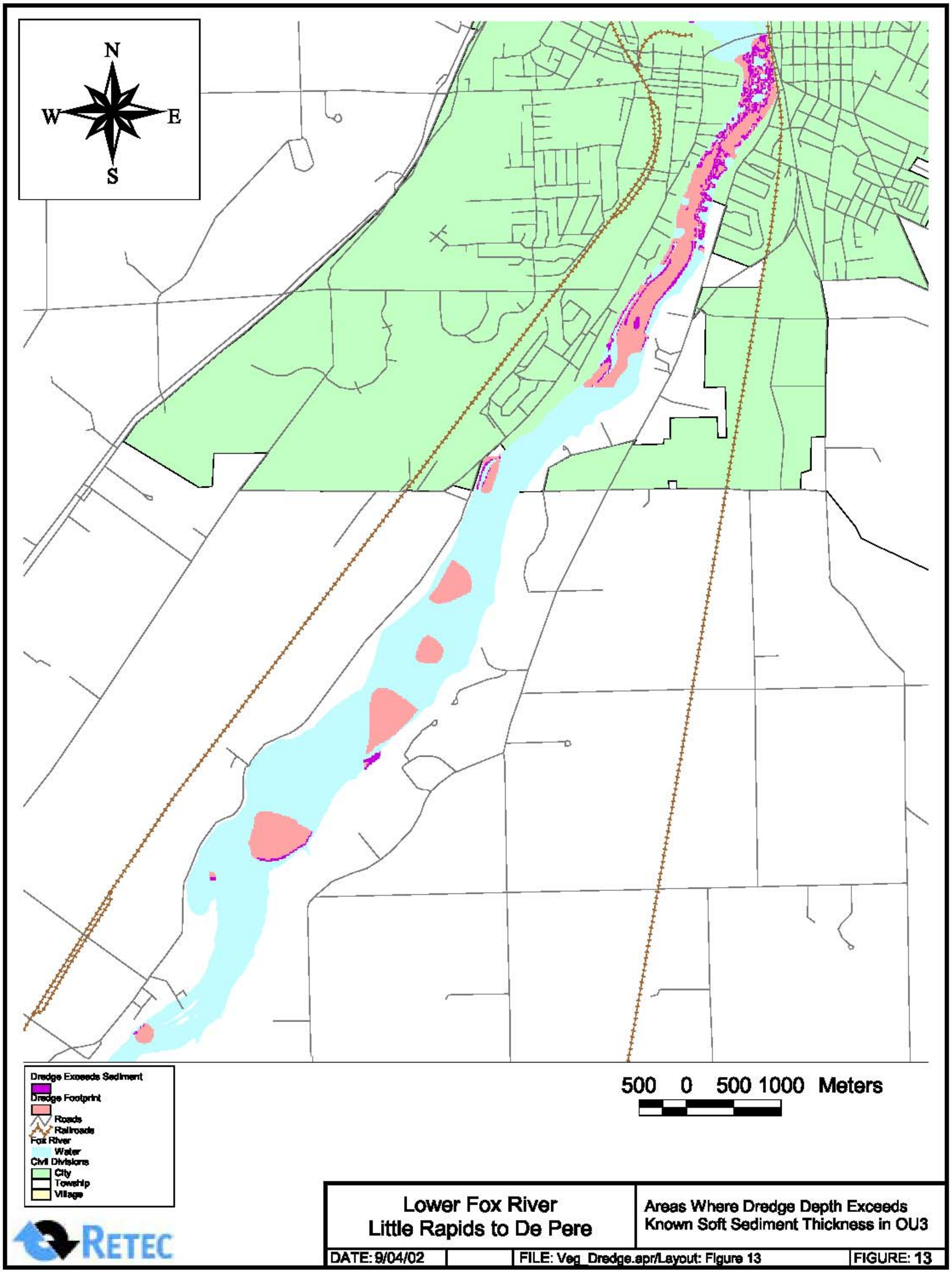
Backwater areas that are associated with tributaries in OUs 3 and 4 will continue to provide suitable habitat for submerged and emergent aquatic vegetation. The presence of dams and locks will sufficiently maintain slower flows necessary for aquatic vegetation establishment. It is likely that aquatic vegetation located in backwater areas and slower flowing environments should reestablish, especially with the upstream seed sources of Little Lake Butte des Morts and Lake Winnebago.

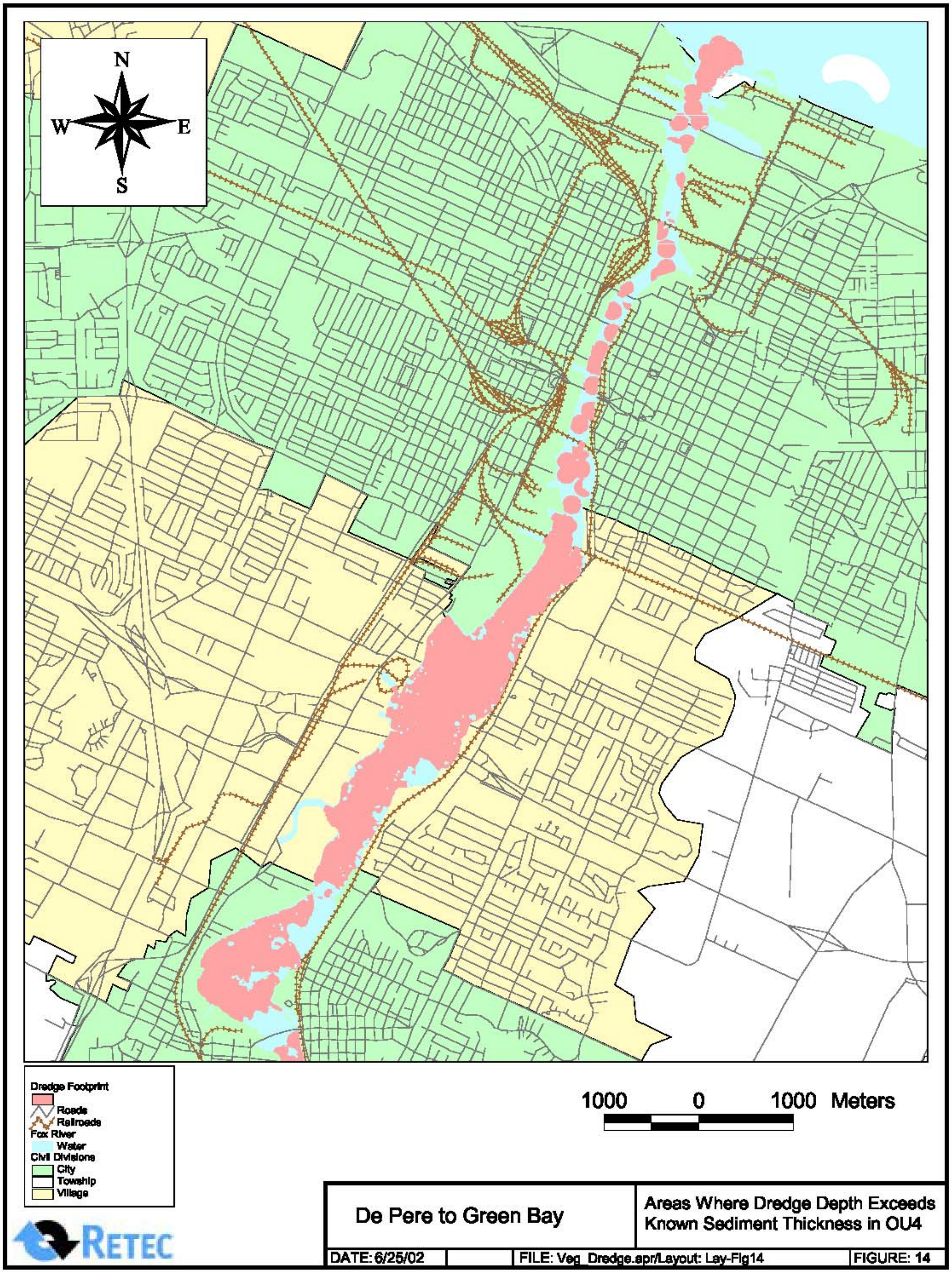
SOFT SUBSTRATE

Dredging sediment in the Lower Fox River has the potential to cause a change in substrate. Different substrates present following dredging could influence the rate and type of recovery of the benthic and aquatic community. In an effort to better identify areas potentially at risk of substrate change, an investigation using a GIS was performed to determine the degree and location of substantive change following dredging. Anticipated dredge depth was summarized in the FS, and sediment thickness was interpolated using a GIS, based on poling data conducted as part of previous sampling activities (RETEC, 2002b). It is assumed that if dredging depth does not exceed sediment thickness, a change in substrate to the stiff, silty clay that is similar to the glacial till in the region will not occur.

Figures 12, 13, and 14 indicate the areas where proposed dredge depth exceeds sediment thickness for OUs 1, 3, and 4. Table 9 shows that approximately 18.3, 14.0, and 31.5 percent of the total dredged area for OUs 1, 3, and 4, respectively, will likely result in substrate changes. Regardless of interpolated dredge depths, dredging into the stiff sediment underlying the soft, upper layers will not occur. Substrate will only change in areas where all soft sediment is targeted for removal.


N
W
E
S
MENASHA
NEENAH
Dredge Exceeds Sediment
Dredge Footprint
Roads
Railroads
Fox River
Water
Civil Divisions
City
Township
Village
500 0 500 1000 Meters
RETEC
Lower Fox River
Little Lake Butte des Morts
Areas where Dredge Depth exceeds known Soft Sediment Thickness (1K PPB)
DATE: 8/30/02
FILE: Veg_Dredge.apr/Layout: Figure 12
FIGURE: 12


N
W
E
S
Dredge Exceeds Sediment
Dredge Footprint
Roads
Railroads
Fox River
Water
Civil Divisions
City
Township
Village
RETEC
500 0 500 1000 Meters
Lower Fox River
Little Rapids to De Pere
Areas Where Dredge Depth Exceeds
Known Soft Sediment Thickness in OU3
DATE: 9/04/02
FILE: Veg_Dredge.apr/Layout: Figure 13
FIGURE: 13


N
W
E
S
Dredge Footprint
Roads
Railroads
Fox River
Water
Civil Divisions
City
Township
Village
1000
0
1000 Meters
RETEC
De Pere to Green Bay
Areas Where Dredge Depth Exceeds Known Sediment Thickness in OU4
DATE: 6/25/02
FILE: Veg_Dredge.apr/Layout: Lay-Fig14
FIGURE: 14

As shown on Figure 12, the majority of the substrate predicted to change is in central Little Lake Butte des Morts. Substrate from a large, undivided dredging section in the northern part of the lake will remain unchanged, as will most of the dredging sections in the northern part of Little Lake Butte des Morts. In OU 3, anticipated substrate change is mostly on the edges of the dredge footprint at the downstream, or northern, end of the reach. Anticipated substrate change in OU 4 is scattered throughout the reach but is concentrated near the central and upstream/southern portions.

Almost one-third of the soft sediment in OU 4 targeted for dredging is anticipated to change to stiff, silty clay following dredging. Dredging for navigational purposes is currently performed by the USACE in OU 4, likely limiting the thickness of soft sediment remaining in the reach. This reach is located below each of the other three reaches and receives additional sediment loads and invertebrates present in the drift from each upstream area. It is likely that sediment deposited from upstream areas will accumulate in backwater and cove areas first and eventually fill in the new, exposed substrate. More than half of the substrate in OU 4 and 80 percent of the substrate in OU 1 and OU 3 will remain unchanged following dredging, allowing quick recolonization of invertebrates to take place.

4.1.2 Removal or Isolation Effects on the Lower Fox River Food Web

Either of the proposed remedies, removal or isolation (dredging or capping), will have no overall impact to the food web. The food chain of the Lower Fox River may be referred to as a pelagic food chain due to the heavy dependence on water column organisms (RETEC, 2002a; Exponent, 1999; LTI Environmental Engineering, 1999), and therefore will likely be unaffected by removal or isolation of benthic organisms. The fish in the Lower Fox River are primarily dependent on water column organisms, and although benthic organisms may be temporarily unavailable, the majority of the food organisms will be present in areas near dredging activities.

The time of year of disturbance may be important to fish populations. Fluctuations in benthic invertebrate, algal, zooplankton, and fish abundances occur seasonally. Blooms of algal populations and resultant zooplankton communities usually occur in spring. Fish species have been found to commonly switch to alternative prey items during initial phases of recovery (Kingsbury and Kreutzweiser, 1987; Warner and Fenderson, 1962). For example, fish estimated to consume oligochaetes and chironomids may be forced to consume zooplankton if oligochaetes and chironomids are temporarily unavailable due to dredging or capping activities.

Secondary consumers like shiners, shad, and perch almost exclusively depend on phytoplankton and zooplankton as food sources. Higher consumers like walleye and rainbow smelt consume shiner and shad. Carp appear to be largely dependent on benthic invertebrates, but have demonstrated flexibility in their diets. Zooplankton are estimated to make up almost half of their diet as adults (Scott and Crossman, 1973). Based on the evidence supporting the dependence on a pelagic based food chain, diets of fishes in the Lower Fox River are likely to be unaffected by dredging or capping activities.

Hydraulic dredging has been used as a means of removing nutrients contained in the sediment in Lake Okeechobee in Florida (SFWMD, 2002). It is thought that dredging decreased the amount of nutrients that could be resuspended to the water column, in turn decreasing the likelihood of algae blooms that normally worsen water clarity. Algae blooms of phytoplankton and filamentous algae can reduce light penetration into the water column, making it more difficult for SAV to establish.

4.1.3 Other Dredging Issues

SUSPENDED SEDIMENTS

Suspended sediments can cause lethal, sublethal, and/or behavioral effects to aquatic receptors. The Lower Fox River is a slow-moving river clouded by naturally occurring suspended sediments; however, dredging or cap placement operations could cause elevated suspended sediment concentrations. The effects of suspended material are summarized for primary producers, invertebrates, and fish in LaSalle et al. (1991); Table 10 highlights causal factors and potential deleterious effects as presented in this paper.

In the dredging pilot project at SMU 56/57, silt curtains were used to prevent the movement of suspended solids downstream. The average turbidity inside the silt curtain was slightly higher than outside the silt curtain (Appendix B, RETEC, 2002b). Also, average turbidity measurements outside of the silt curtain were not appreciably different between upstream and downstream locations. Suspended solids resulting from dredging at SMU 56/57 has minimal effect on organisms located inside and outside the silt curtain (Appendix B, RETEC, 2002b).

Dredging will likely have little to no affect on the phytoplankton and zooplankton communities due to the high amount of suspended sediments already present in the Lower Fox River. Additional suspended material can reduce photosynthetic activity due to the interference of light penetration, but additional nutrients may be released to the water column as a result of dredging, thus serving to increase the plankton biomass (Stern and Stickle, 1978). Because of the dependence on water column organisms, this effect is likely to provide additional food resources to the aquatic and benthic community of the Lower Fox River.

Dredging should not cause fish present in the Lower Fox River to be subjected to higher levels of suspended sediments than are already present in the River. Many studies have been devoted to the effects of suspended material on the reproduction, growth, and development of fishes. Extensive general and supplementary bibliographies on the effects to fish are provided in Plumb (1973). Schubel and Wang (1973) found that in a relatively well-mixed environments, concentrations of natural fine-grained suspended sediment up to about 500 mg/L would not affect hatching success of yellow perch, white perch, striped bass, or alewife. Auld and Schubel (1978) found that survival was reduced above 500 mg/L for yellow perch and striped bass and above 100 mg/L for alewife. (See Table 3 for background and maximum concentrations for Lower Fox River demonstration projects N and SMU 56/57.)

TABLE 10 DREDGING EFFECTS

Organism	Life Stage	Causal Factors	Effect
Fish	Eggs	▪ Entrainment and mechanical abrasion of egg and larvae ▪ Reduction of available light ▪ Sorption of contaminants carried by sediments ▪ Interference with feeding ▪ Smothering ▪ Increased exposure to toxic compounds	▪ Hatching success ▪ Delayed and/or asynchrous development
	Larvae	▪ Loss of chorion protection ▪ Adhesion of particles to epidermis impairing respiration ▪ Abrasive damage to gills and epidermis ▪ Entrainment ▪ Increased exposure to toxic compounds	▪ Mortality with reduced survival occurring at ≥ 100 – 500 mg/L for some species
	Adults	▪ Interference with respiration and feeding ▪ Increased exposure to toxic compounds	▪ Behavioral distress ▪ Disrupted gill tissue and increased mucous production in white perch at 650 mg/L (Sherk et al., 1975) ▪ Lethal turbidity > 16,500 mg/L for 16 species of fresh water fish (Wallen, 1951)
Benthic Invertebrates		▪ Burial ▪ Changes in grain size, slope, compaction ▪ Blocking of chemical cues (i.e., pheromones) ▪ Respiration and feeding interference ▪ Decreased light interfering with larval settling site cues ▪ Increased exposure to toxic compounds	▪ Mortality ▪ Interference with reproduction and recruitment
Algae and SAV		▪ Decreased light ▪ Respiration interference ▪ Increased exposure to toxic compounds	▪ Reduced photosynthetic capabilities ▪ Variable responses to increased exposure toxic compounds

FISH AVOIDANCE/ENTRAINMENT

Fish are usually quite mobile, allowing them to avoid the disturbance and actively seek out undisturbed areas containing refugia. Sufficient refugia located in undredged areas (areas targeted in the future or untargeted areas) should be available as fish avoid dredging activities. However, fish eggs may be susceptible to entrainment by suction dredges when they come in contact with the suction field around the intake pipe (McNair and Banks, 1986).

Small numbers of fish entrainment can occur during dredging activities. Entrainment rates in Grays Harbor range from 0.001 to 0.135 fish per cubic yard (fish/cy) (Armstrong et al., 1981) and from 0.001 to 0.38 fish/cy for material dredged in the mouth of the

Columbia River, Oregon, and Washington (Larson and Moehl, 1990). For several fish species studied in Grays Harbor, Washington, Armstrong et al. (1981) found large and small fish to be entrained in similar proportions, indicating that large fish did not actively avoid the dredge any more effectively than smaller fish. None of the fish that were entrained is a species found in the Lower Fox River due to the estuarine environment of the study areas. However, the potential for entrainment may increase if operations occur during migration periods in heavily used narrow-channel habitats (Lasalle et al., 1991), although narrow-channel habitats of the Lower Fox River typically contain faster flowing water and are composed primarily of harder substrates not targeted for dredging.

4.1.4 Reestablishment Following Removal or Isolation

Direct removal of sediment or placement of a cap would likely alter the benthic invertebrate community. The pelagic food web of the Lower Fox River will likely not be affected by dredging or capping; however, fish spawning habitat (as discussed above) and benthic invertebrate community composition could be affected. Benthic organisms may be removed or buried, and substrate type may change. These issues and factors influencing recovery are discussed further below.

SUMMARY OF RECOVERY FOLLOWING DREDGING IN THE LOWER FOX RIVER

The Lower Fox River aquatic trophic structure is largely dependent on water column organisms, however, benthic invertebrates like oligochaetes and chironomids provide some food for several species of fish and birds. The large dependence of the Lower Fox River community on water column organisms mitigates the effect of depressed benthic invertebrate populations as a result of dredging or capping. Fish are generally able to avoid dredging activities and relocate to habitat suitable for their feeding and reproductive needs. Fish present in the Lower Fox River already migrate to reaches with suitable habitat for spawning or to escape seasonally unfavorable temperature and dissolved oxygen concentrations (Hynes, 1970). Fish populations will return to disturbed areas previously occupied as benthic invertebrate communities reestablish. Evidence collected from pilot studies indicates that recovery of benthic invertebrates is rapid following sediment removal.

Many upstream invertebrate sources are present in the Lower Fox River. Surveys conducted throughout the entire reach of Little Lake Butte des Morts and in OUs 2, 3, and 4 have indicated that chironomids and oligochaetes are the most prevalent organisms throughout the entire River (IPS, 1993a, 1993b, 2000a, 2000b, 2000c; WDNR, 1996). The dredging footprint shown on Figure 9 indicates areas that are not targeted for dredging in Little Lake Butte des Morts. The extended dredging schedule will also allow for organisms within the 1-ppm footprint yet to be dredged to serve as source populations for adjacent areas already dredged. The types and proximities of undisturbed areas near the dredged areas will likely provide substantial sources for recolonization. The areas not proposed for dredging have more coarse substrates that generally host more diverse benthic invertebrate populations. It is highly probable that these organisms will migrate to dredged areas as part of the drift due to the consistent populations present in Lake Winnebago and OU 2.

Chironomids are a major component of the drift (Waters, 1972). In addition to drift, chironomids, which have one or more generations per year in a population, will likely also utilize aerial colonization pathways (Brundin, 1967). Substantial evidence is present to indicate that chironomids will recolonize the disturbed area. Chironomids have been found to be some of the earliest colonizers in experiments in streams (Waters, 1964; Gray and Fisher, 1981). New stream channels devoid of any invertebrate organisms appear to be quickly colonized by chironomids (Malmqvist et al., 1991). They recovered quickly in the lowland River Hull in areas with and without the establishment of aquatic vegetation following dredging (Pearson, 1984). In an experiment of defaunated sediment in Lake Erie, one species of chironomid and oligochaete established at abundances of two to seven times their natural abundances when compared to the nearby undisturbed community within 40 days; however, their abundances decreased later (Soster and McCall, 1990). Other chironomids reached their natural abundances quickly but did not exceed them.

In SMU 56/57, oligochaetes and chironomids appear to recolonize quickly despite shifts to substrate with greater proportions of clays and silts. Areas of sediment where benthic invertebrates were completely eliminated recovered within 9 months with an increased proportion of oligochaetes and increased numbers of both oligochaetes and chironomids (IPS, 2000c). In several of the dredging case studies, oligochaetes recolonized to levels greater than before dredging. In Wisconsin spring ponds, dredging removed the soft, organic sediment, exposing marl substrate and allowing oligochaetes to reestablish quickly and in much greater numbers than originally present (Carline and Brynildson, 1977). Considering the information contained in the case studies, regardless of the substrate change, oligochaetes and chironomids will quickly and fully reestablish.

SUMMARY OF RECOVERY FOLLOWING CAPPING IN THE LOWER FOX RIVER

The effects of capping on the Lower Fox River habitat and benthic macroinvertebrate community are similar to that of dredging. It may even have a more significant effect on the community because of the distinct change in substrate. The combinations of sand and gravel in proposed caps have low organic carbon due to the isolation of detritus already deposited and decomposing in the original sediment. The most common burrowing organisms like chironomids and oligochaetes depend on organic material for food. Chironomids are detritovores that depend on organic material in their first instar, but many become carnivorous as they grow older, with their diet being highly variable and opportunistic (Kajak and Dusoge, 1970). Oligochaetes are widespread but thrive in muds rich in organic matter (Poddubnaya, 1979).

Oligochaetes typically become more common in relation to chironomids as lakes become more productive, or eutrophic (Wetzel, 1983). More productive lakes contain added organic matter in the form of phytoplankton, vegetation, and algae that decomposes to form organic sediment. The addition of a sand and gravel cap low in organic carbon and detritus would likely provide a substrate unsuitable for chironomid and oligochaete establishment until organic rich sediment could be deposited after the cap was laid. This occurred following shifts in substrate to a sand cap in the highly productive Inlet Basin of Soda Lake in Wyoming, allowing colonization of oligochaetes and chironomids to reach levels similar to uncapped areas of the lake (ThermoRetec, 2001).

Many chironomids and oligochaetes also live on and around SAV. Because of the lack of organic material in a potential sand or gravel cap, SAV will likely not reestablish in areas where it was present prior to dredging until sufficient organic material accumulates on the cap. Seeds contained in the drift may settle in the sand or gravel cap; however, they are less likely to settle and stick in the non-organic substrate. Chironomids and oligochaetes will be present in lower abundance where SAV beds were previously present, decreasing the possibility that adult and juvenile fish will inhabit the area because of deficiencies in cover and food.

One of the limits imposed on potential capping sites within the River was that new carp spawning habitat not be created by increasing lake bottom elevations (see *White Paper No. 6B – In-Situ Capping as a Remedy Component for the Lower Fox River*).

5 CONCLUSION

The key points contained in this report are as follows:

- Potential impacts to habitat should be a consideration when selecting remedial actions, but restoration is not an RAO.

  In the case of the Lower Fox River, the major habitat considerations that emerge are a potential change in substrate type for benthic organisms, potential loss of valuable marshland, and potential positive or negative impacts to spawning habitat for fish species. These potential impacts are discussed more below, but the salient point is that habitat is only a consideration, not an objective. RAOs, in the FS, were set to govern the eventual outcome of remedial actions on the River. Habitat restoration is a function of a separate activity being conducted under the NRDA settlement.

- Dredging and capping, both locally and nationally, have been shown to have minimal impact on aquatic communities.

  The key consideration for any remedial action is that the food chain of the Lower Fox River is pelagic, or based on water column organisms. Changing the substrate through either dredging or capping will not cause any appreciable change in the food chain production.

  Dredging sediments in the Lower Fox River may cause habitat changes, however, these effects are temporary and only mildly affect the organisms currently living in the Lower Fox River. In the case of Deposit N, the residual habitat 2 years after dredging included some new sediment, but was largely well scoured and included larger, cobble-like material. In the case of SMU 56/57, the benthic recovery was very rapid, and within 2 years there was 5 feet of sediment accumulation.

  There are no caps placed in any riverine system with demonstrated, long-term monitoring of effectiveness anywhere in the world, so conclusions about the ecological effects of capping can only be inferred from marine-placed caps, or in the relatively few and recent freshwater lake cap systems. Any cap placed within the Lower Fox River will alter the benthic community, but its long-term effect will be dependent upon whether the area is a depositional or scour environment.

- Both dredging and capping have the potential to resuspend sediments, but the levels of resuspended solids and PCBs are lower than those naturally occurring on the Lower Fox River.

  Numerous national and international studies confirm that the short-term effects of resuspension are negligible. The longer-term effects of PCBs transported downstream are covered in a separate White Paper, but are considered to be minor, relative to the effects of leaving existing PCBs in place.

- Benthic invertebrates are in low diversity in the Lower Fox River and, as evidenced by the case studies provided, recovery may occur quickly in depositional areas of the Lower Fox River following dredging activities.

  Areas of scour may take longer to recover to pre-dredge conditions. Capping will alter the local benthic communities over the short term, given the need to provide final armor covering in any option. Caps may enhance, or depress local benthic production, depending upon the final substrate selected and whether the environment is depositional or scour. Over longer periods, sediment loads in depositional areas will fill in over the gravel or cobble armor layers, restoring pre-action benthic substrate conditions.

- Marsh habitat is an important and sparse asset on the Lower Fox River. Any remedial alternative should weigh the environmental risks from PCBs left in place to the risks of loss of habitat.

  There are very few areas where rooted SAV still exist within the Lower Fox River system. The current dredging or capping proposals would in some cases negatively impact these marshes. Where these exist, consideration should be given to the relative risk of leaving PCBs in place, allowing natural attenuation to occur, against the risk of loss of habitat. In Little Lake Butte des Morts, the marshland around Stroebe Island has been identified by the WDNR as a valuable spawning habitat for bluegill, sunfish, and bass, and the last remnant of northern pike spawning ground; and should not be a part of any ultimate removal or capping action.

  While PCBs have been measured above the RAL (1 ppm) in a relatively small area proximal to those wetlands (Deposit F), careful consideration should be made as to how, or if those should be managed. By contrast, a bed of water lilies does exist over Deposit A, where concentrations have been reported in the tens to hundreds of ppm.

  At these levels, the consideration should be for removal to manage ecological and human health risks from PCB exposure, and to plan for a restoration activity under the NRDA.

  Consideration also should be given to whether the observed SAV is actually valuable habitat, or an undesired exotic species. Again, within Little Lake Butte des Morts a considerable amount of the acreage identified in other reports as SAV is in fact Eurasian water milfoil, an exotic and/or eutrophic species that adversely affects both the benthic invertebrate and fish communities.

- Fish will not be affected by any of the proposed remedial alternatives.

  Fish are likely to neither be positively or negatively impacted by the dredging or capping remedial alternatives currently under consideration. Studies conducted by the USACE and others have repeatedly documented that fish are mobile species that will avoid disturbed areas and can reestablish in other readily available, suitable habitat. Successful management of fish spawning periods has been accomplished for many states and dredging projects by setting seasonal restrictions. Furthermore, case studies in Wisconsin suggest that removal of PCB-contaminated sediments may at least temporarily enhance the habitat by removing phosphorus and nitrogen that contribute to eutrophication in the River.

  Finally, critical habitat for desired game species such as walleye or bass on the Lower Fox River are outside of the areas proposed for removal.

- The type of habitat enhancements consistently called for by WDNR and the Proposed Plan are those that would support the diversification of the fish assemblages within the River and the creation of more nearshore, shallow littoral habitat.

  The Lower Fox River already supports a world-class walleye fishery, and the spawning and nursery areas for those fish are not affected by proposed removal operations, and not enhanced by armoring proposals for capping.

  Capping likely will have similar effects of dredging on aquatic vegetation and benthic invertebrate and fish communities; however, recovery of benthic invertebrate communities likely will be slower than recovery following dredging due to decreased organic content of the sediment.

  Benthic invertebrates are in low diversity in the Lower Fox River and, as evidenced by the case studies provided, will recover quickly in the Lower Fox River following dredging activities.

  SAV is only present in 29.9 percent of Little Lake Butte des Morts, much of which is not targeted for dredging, which provides sufficient cover and spawning habitat before, during, and after dredging.

- Multiple years of monitoring may be required to determine enhancements or detriments to the benthic habitat.

6 REFERENCES

Aldridge, D. C., 2000. The impacts of dredging and weed cutting on a population of freshwater mussels (Bivalvia: Unionidae). *Biolog. Conserv*. 95:247–257.

Allen, K. O. and J. W. Hardy, 1980. *Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review*. Prepared by Biological Services Program, United States Fish and Wildlife Service. FWS/OBS-80/07. 80 p.

Armstrong, D. A., Stevens, B. G., and J. C. Hoeman, 1981. *Distribution and Abundance of Dungeness Crab and Crangon Shrimp and Dredging-Related Mortality of Invertebrates and Fish in Grays Harbor, Washington*. Report No. DA-80-86. Washington Department of Fisheries and United States Army Engineer District, Seattle, Washington. As cited in USACE, 1998. *Entrainment by Hydraulic Dredges – A Review of Potential Impacts*. Technical Note DOER-E1. United States Army Corps of Engineers. December.

Arner, D. H., H. R. Robinette, J. E. Fraiser, and M. H. Gray, 1976. *Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water Quality, and Furbearers*. Office of Biological Services, Fish and Wildlife Service, United States Department of the Interior, Washington, D.C. 58 p. As cited in Milner, A. M., 1994. Chapter 5: System Recovery. In: *The Rivers Handbook, Volume II*. P. Calow and G. Petts (eds). Blackwell Scientific Publications, Oxford, England.

Auer, M. T., T. M. Heidtke, and R. P. Canale, 1985. Trophic state response to nonpoint pollution control: Application of coupled microcomputer models to the Great Lakes. *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference, Kansas City, Missouri, May 19–22, 1985*. p. 147–152

Auld, A. H. and J. R. Schubel, 1978. Effects of suspended sediments on fish eggs and larvae: A laboratory assessment. *Estuarine, Coastal, and Marine Science*. 6:153–164.

Becker, G. C., 1983. *Fishes of Wisconsin: Trout, Herring, Perch, Minnow, Carp*. The University of Wisconsin Press, Madison, Wisconsin.

Brazner, J. C. and J. J. Magnuson, 1994. Patterns of fish species richness and abundance in coastal marshes and other nearshore habitats in Green Bay, Lake Michigan. *International Association of Theoretical and Applied Limnology*. 25:2098–2104.

Brundin, L., 1967. Insects and the problem of austral disjunctive distribution. *Annual Review of Entomology*. 12:149–168.

Carlander, K. D., 1997. Chapter 7: Yellow perch, *Perca flavescens* (*Mitchill*). *Handbook of Freshwater Fishery Biology*. Iowa State University Press, Ames, Iowa. 3:125–179.

Carline, R. F. and O. M. Brynildson, 1977. *Effects of Hydraulic Dredging on the Ecology of Native Trout Populations in Wisconsin Spring Ponds*. Technical Bulletin No. 98. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Cattaneo, A. and J. Kalff, 1980. The relative contribution of aquatic macrophytes and their epiphytes to the production of macrophyte beds. *Limnol. Oceanogr*. 25:280–289.

Clarke, D. G. and D. H. Wilber, 2000. *Assessment of Potential Impacts of Dredging Operations Due to Sediment Resuspension*. DOER Technical Notes Collection, ERDC TN-DOER-E9. United States Army Corps of Engineers Research and Development Center, Vicksburg, Mississippi.

Cochran, P. A., 1992. The return of *Hexagenia* (Ephemoeroptera: Ephemeridae) to the lower Fox River, Wisconsin. *Great Lakes Entomologist*. 25:79–81.

Cochran, P. A. and A. P. Kinziger, 1997. *Hexagenia bilineata* (Ephemoeroptera: Ephemeridae) persists at low levels of abundance in the lower Fox River, Wisconsin. *Great Lakes Entomologist*. 30:89–92.

Detenbeck, N. E., P. W. DeVore, G. J. Niemi, and A. Lima, 1992. Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. *Environmental Management*. 16(1):33–53.

Edwards, C. J., B. L. Griswold, R. A. Tubb, E. C. Weber, and L. C. Woods, 1984. Mitigating effects of artificial riffles and pools on the fauna of a channelized warmwater stream. *North American Journal of Fisheries Management*. 4:194–203.

Engel, S., 1995. Eurasian water milfoil as a fishery management tool. *Fisheries*. 20(3):20–27.

Environment Canada, 1998. *The Remediation Technologies Program Great Lakes 2000 Cleanup Fund Technical Report*. Environment Canada, Environmental Protection Branch, Ontario Region, Ontario. March.

EPA, 1990. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters*. Publication EPA/600/4-90/030. Office of Research and Development, Washington, D.C. November.

Exponent, 1998. *Habitat Characterization for the Lower Fox River and Green Bay Assessment Area*. Prepared for The Fox River Group and Wisconsin Department of Natural Resources. September.

Exponent, 1999. *The Use of Habitat Characterization and Food Web Modeling in the Evaluation of Remedial Alternatives*. Prepared for the Fox River Group and Wisconsin Department of Natural Resources. Landover, Maryland.

Foth and Van Dyke, 2000. *Summary Report: Fox River Deposit N*. Prepared for the Wisconsin Department of Natural Resources, Madison, Wisconsin.

FRRAT, 2000. *Evaluation of the Effectiveness of Remediation Dredging: The Fox River Deposit N Demonstration Project November 1998–January 1999*. University of Wisconsin Water Resources Institute Special Report WRI SR 00-01.

Giller, P. S., N. Sangpradub, and H. Twomey, 1991. Catastrophic flooding and macroinvertebrate community structure. *Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie*. 24:1724–1729. As cited in Milner, A. M., 1994. Chapter 5: System Recovery. In: *The Rivers Handbook, Volume II*. P. Calow and G. Petts (eds). Blackwell Scientific Publications, Oxford, England.

Gore, J. A., 1979. Patterns of initial benthic recolonization of a reclaimed coal strip-mined river channel. *Canadian Journal of Zoology*. 57:2429–2439.

Gray, L. G. and S. G. Fisher, 1981. Postflood recolonization pathways of macroinvertebrates in a lowland Sonoran Desert stream. *American Midland Naturalist*. 106:249–257.

Great Lakes RAP, 1996. *Draft Proposal: Habitat Restoration in Lower Green Bay of Lake Michigan Feasibility Study and Engineering Design, Great Lakes Remedial Action Plans*. Wisconsin Department of Natural Resources – Lake Michigan District.

Guannel, G., T. Wang, S. Cappellino, and C. Boudreau, 2002. Resuspended sediment effects in aquatic environments from dredging operations. *Proceedings of the Western Environmental Dredging Association Twenty-Second Technical Conference, June 12–15, 2002, Denver, Colorado*. p. 165–178.

Gustin, M. A., 1995. Source, Transport and Fate of Sediments and Nutrients in the Winnebago Pool System. Ph.D. Thesis prepared for the University of Wisconsin at Milwaukee.

Harrod, J. J., 1964. The distribution of invertebrates on submerged aquatic plants in a chalk stream. *Journal of Animal Ecology*. 33:335–341.

Harvey, B. C. and T. E. Lisle, 1998. Effects of suction dredging on streams: A review and an evaluation strategy. *Fisheries*. 23(8):8–17.

Herbich, 2000. *Handbook of Dredging Engineering, 2nd Edition*. McGraw-Hill, New York.

Hirsch, N. D., L. H. DiSalvo, and R. Peddicord, 1978. *Effects of Dredging and "Disposal on Aquatic Organisms*. Technical Report DS-78-5. United States Army Corps of Engineers Waterways Experiment Station, Springfield, Virginia.

Honnell, D., J. D. Madsen, and R. M. Smart, 1992. Effects of aquatic plants on water quality in pond ecosystems. In: *Proceedings: 26th Annual Meeting, Aquatic Plant Control Research Program*. Report A-92-2. United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Hortle, K. G. and P. S. Lake, 1982. Macroinvertebrate assemblages in channelized and unchannelized sections of the Bunyip River, Victoria. *Australian Journal of Marine and Freshwater Research*. 33:1071–1082.

Hunt, R. L., 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. *Transactions of the American Fisheries Society*. 105:361–364.

Hynes, H. B. N., 1970. *The Ecology of Running Waters*. University of Toronto Press, Toronto, Ontario, Canada. 555 p.

IPS, 1993a. *Benthic Community Characterization in Little Lake Butte des Morts, Winnebago County, Wisconsin – 1992*. Integrated Paper Services, Inc., Appleton, Wisconsin. Project 5058. 49 p.

IPS, 1993b. *Benthic Community Component, Fox River Sediment Quality Triad Assessment – 1992*. Integrated Paper Services, Inc., Appleton, Wisconsin. Project 5064. 36 p.

IPS, 1994. *Benthic Community Component, Fox River Sediment Quality Triad Assessment – 1993*. Integrated Paper Services, Inc., Appleton, Wisconsin. June 15.

IPS, 2000a. *A Benthos Inventory of the Lower Fox River, Sediment Management Unit 56/57, Pre-Dredging Conditions, 1999*. Integrated Paper Services, Inc. Project 5025.

IPS, 2000b. *A Benthos Inventory of the Lower Fox River, Sediment Management Unit 56/57, 1st Post-Dredging Survey, 2000*. Integrated Paper Services, Inc. Project 5025.

IPS, 2000c. *A Benthos Inventory of the Lower Fox River, Sediment Management Unit 56/57, 2nd Post-Dredging Survey, 2000*. Integrated Paper Services, Inc. Project 5025.

Kaenel, B. R., Matthaei, C. D., and U. Uehlinger, 1998. Disturbance by aquatic plant management in streams: Effects on benthic invertebrates. *Regulated Rivers: Research and Management*. 14:341–356.

Kajak, Z. and K. Dusoge, 1970. Production efficiency of *Procladius choreus* MG (Chironomidae, Diptera) and its dependence on the trophic conditions. *Pol. Arch. Hydrobiol*. 17:217–224.

Keast, A. 1984. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their macroinvertebrate prey. *Can. J. Zool*. 62:1289–1303.

Kingsbury, P. D. and D. P. Kreutzweiser, 1987. Permethrin treatments in Canadian forests, Part 1: Impact on stream fish. *Pesticide Science*. 19:35–48.

Lambert, T. R., 1988. Recolonization of a small stream by rainbow trout following a flood event. In: *68th Annual Conference of the Western Association of Wildlife Agencies.* Western Division, American Fisheries Society, Albuquerque. p. 258–264. As cited in Milner, A. M., 1994. Chapter 5: System Recovery. In: *The Rivers Handbook, Volume II*. P. Calow and G. Petts (eds). Blackwell Scientific Publications, Oxford, England.

Larson, K. W. and C. E. Moehl, 1990. Entrainment of anadromous fish by hopper dredging at the mouth of the Columbia River, Oregon and Washington. In: *Effects of Dredging on Anadromous Pacific Coast Fishes: Workshop Proceedings.* University of Washington and Washington Sea Grant Program. p. 100–110.

LaSalle, M., D. Clarke, J. Homziak, and J. Fredette, 1991. *A Framework for Assessing the Need for Seasonal Restrictions on Dredging and Disposal Operations*. Technical Report D-91-1. United States Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Lillie, R. A. and J. Budd, 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. *Journal of Freshwater Ecology*. 7(2):113–125.

LTI Environmental Engineering, 1999. *Fox River and Green Bay Fate and Transport Model Evaluation: Technical Memorandum 2b – Computation of Watershed Solids and PCB Load Estimates for Green Bay*. Ann Arbor, Michigan.

Lychwick, T. L., 1995. Fox River walleye habitat improvement. In: *Methods of Modifying Habitat to Benefit the Great Lakes Ecosystem*. J. R. M. Kelso and J. H. Hartig (eds). National Research Council of Canada, Ottawa, Canada.

Lychwick, T., 2002. Personal communication from Fisheries Biologist, Wisconsin Department of Natural Resources, Green Bay, Wisconsin. September.

Mackay, R. J., 1992. Colonization by lotic macroinvertebrates: A review of processes and patterns. *Can. J. Fish. Aquat. Sci*. 49:617–628.

Madsen, J. D., R. M. Smart, G. O. Dick, and D. R, Honnell, 1995. The influence of an exotic submersed aquatic plant, *Myriophyllum spicatum*, on water quality, vegetation, and fish populations of Kirk Pond, Oregon. In: *Proceedings: 29th Annual Meeting, Aquatic Plant Control Research Program*. United States Army Corps of Engineers, Waterways Experiment Station.

Malmqvist, B., S. Rundle, C. Bronmark, and A. Erlandson, 1991. Invertebrate colonization of a new, man-made stream in southern Sweden. *Freshwater Biology*. 26:307–324.

Matthews, W. J., 1986. Fish faunal structure in an Ozark stream: Stability, persistence and a catastrophic flood. *Copeia*. p. 388–397.

McNair, E. C. and G. E. Banks, 1986. Prediction of flow fields near the suction of a cutterhead dredge. *American Malacological Bulletin, Special Edition*. 3:37–40. As cited in LaSalle, M., D. Clarke, J. Homziak, and J. Fredette, 1991. *A Framework for Assessing the Need for Seasonal Restrictions on Dredging and Disposal Operations*. Technical Report D-91-1. United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Milner, A. M., 1987. Colonization and ecological development of new streams in Glacier Bay National Park, Alaska. *Freshwater Biology*. 18:53–70.

Milner, A. M., 1994. Chapter 5: System Recovery. In: *The Rivers Handbook, Volume II*. P. Calow and G. Petts (eds). Blackwell Scientific Publications, Oxford, England. p. 76–97.

Minshall, G. W., D. A. Andrews, and C. Y. Manuel-Faler, 1983. Application of island biogeographic theory to streams: Macroinvertebrate recolonization of the Teton River, Idaho. In: *Stream Ecology: Application and Testing of General Ecological Theory.* Barnes, J. R. and G. W. Minshall (eds). Plenum Press, New York. p. 279–297.

Minshall, G. W. and R. C. Peterson, Jr., 1985. Towards a theory of macroinvertebrate community structure in stream ecosystems. *Archiv. Hydrobiol*. 104(1):49–76. July.

Nature Conservancy, 1994. *The Conservation of Biological Diversity in the Great Lakes Ecosystem: Issues and Opportunities*. Great Lakes Program, 8 South Michigan Avenue – Suite #2301, Chicago, Illinois 60603. Website: http://www.epa.gov/glnpo/ecopage/issues.html.

Niemi, G. J., P. DeVore, N. Detenbeck, D. Taylor, A. Lima, J. Pastor, D. Yount, and R. Naiman, 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management*. 14(5):571–587.

Pearson, R. G., 1984. Temporal changes in the composition and abundance of the macro-invertebrate communities of the River Hull. *Archiv fur Hydrobiologie*. 100:273–298.

Plumb, R. H., 1973. A study of the potential effects of the discharge of taconite tailings on water quality in Lake Superior. Ph. D. Thesis, University of Wisconsin, Madison.

Poddubnaya, T. L., 1979. Life cycles of mass species of tubificidae (Oligochaeta). In: *Aquatic Oligochaete Biology*. Brinkhurst, R. O. and D. G. Cook (eds). Plenum Press, New York.

RETEC, 2002a. *Final Remedial Investigation for the Lower Fox River and Green Bay, Wisconsin*. Prepared for Wisconsin Department of Natural Resources by The RETEC Group, Inc., St. Paul, Minnesota. December.

RETEC, 2002b. *Final Feasibility Study for the Lower Fox River and Green Bay, Wisconsin*. Prepared for Wisconsin Department of Natural Resources by The RETEC Group, Inc., Seattle, Washington. December.

RETEC, 2002c. *Final Baseline Human Health and Ecological Risk Assessment for the Lower Fox River and Green Bay, Wisconsin, Remedial Investigation and Feasibility Study*. Prepared for Wisconsin Department of Natural Resources by The RETEC Group, Inc., Seattle, Washington and Pittsburgh, Pennsylvania. December.

Schubel, J. R. and J. C. S. Wang, 1973. *The Effects of Suspended Sediment on the Hatching Success of Perca flavescens (Yellow Perch), Morone americana (White Perch), Morone saxatilus (Striped Bass), and Alosa Pseudoharengus (Alewife) Eggs.* Special Report 30. Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Maryland. As cited in Guannel, G., T. Wang, S. Cappellino, and C. Boudreau, 2002. Resuspended sediment effects in aquatic environments from dredging operations. In: *Proceedings, Western Dredging Association Twenty-Second Technical Conference, Denver Colorado, June 12–15*.

Scott, W. B. and E. J. Crossman, 1973. *Freshwater Fishes of Canada*. Bulletin 184. Fisheries Research Board of Canada, Ottawa, Canada.

SFWMD, 2002. *Lake Okeechobee Pilot Dredging Program*. South Florida Water Management District. Website: http://www.sfwmd.gov/org/wrp/wrp_okee/projects/pilotdredging.html.

Sherk, J. A., J. M. O'Connor, and D. A. Neumann, 1975. Effects of suspended and deposited sediments on estuarine environments. *Estuarine Research, Vol. II*. Academic Press, New York. p. 541–558.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie, 1982. *Manual of Stream Channelization Impacts on Fish and Wildlife*. FWS/OBS-82/24. Office of Biological Services, Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

Snyder, G. R., 1976. Effects of dredging on aquatic organisms, with special application to areas adjacent to the Northeaster Pacific Ocean. *Marine Fisheries Review*. 38(11):34–38.

Soster, F. M. and P. L. McCall, 1990. Benthos response to disturbance in western Lake Erie: Field experiments. *Can. J. Fish. Aquat. Sci*. 47:1970–1985.

Steinman, A. D. and C. D. McIntire, 1990. Recovery of lotic periphyton communities after disturbance. *Environmental Management*. 14(5):589–604.

Stern, E. M. and W. B. Stickle, 1978. *Effects of Turbidity and Suspended Material in Aquatic Environments Literature Review*. Technical Report D-78-21. Office, Chief of Engineers, United States Army, Washington, D.C. As cited in Guannel, G., T. Wang, S. Cappellino, and C. Boudreau, 2002. Resuspended sediment effects in aquatic environments from dredging operations. In: *Proceedings, Western Dredging Association Twenty-Second Technical Conference, Denver Colorado, June 12–15*.

Stivers, C. E. and R. Sullivan, 1994. Restoration and capping of contaminated sediments. In: *Dredging '94: Proceedings of the Second International Conference on Dredging and Dredged Material Placement, 14–16 November 1994, Orlando, Florida*. E. C. McNair, Jr. (ed). American Society of Civil Engineers, New York, New York. p. 1017–1026.

Szymanski, S., 2000. Personal communication from Wisconsin Department of Natural Resources regarding zebra mussels and wetlands in the Lower Fox River and Green Bay. June 22.

The Johnson Company, 2002. *Ecosystem-Based Rehabilitation Plan – An Integrated Plan for Habitat Enhancement and Expedited Exposure Reduction in the Lower Fox River and Green Bay*. Prepared for Appleton Papers, Inc. by The Johnson Company. January.

ThermoRetec, 2001. *Cap Demonstration Project – BP Soda Lake Site, Casper, Wyoming*. Prepared for BP by ThermoRetec Consulting Corporation, Seattle, Washington. November 17.

USACE, 2002. Environmental Effects and Dredging and Disposal (E2D2) Database. United States Army Corps of Engineers Website: http://www.wes.army.mil/el/e2d2/index.html.

USFWS, 1982. *Habitat Suitability Index Models: Common Carp*. FWS/OBS-82/10.12. United States Department of the Interior, Fish and Wildlife Service.

USFWS, 1983. *Habitat Suitability Information: Yellow Perch*. Publication FWS/OBS-82/10.55. United States Department of the Interior, Fish and Wildlife Service.

USFWS, 1984. *Habitat Suitability Information: Walleye*. Publication FWS/OBS-82/10.56. United States Department of the Interior, Fish and Wildlife Service.

USGS, 2002. Nonindigenous Aquatic Species: *Myriophyllum spicatum*. United States Geological Survey Website: http://nas.er.usgs.gov/plants/docs/my_spica.html.

Wallace, J. B., 1990. Recovery of lotic macroinvertebrate communities from disturbance. *Environmental Management*. 14(5):605–620.

Wallen, I. E., 1951. The direct effect of turbidity on fishes. *Bulletin of the Oklahoma Agricultural College, Biological Series 2*. 48:1–27.

Warner, K. and O. C. Fenderson, 1962. Effects of DDT spraying for forest insects on Maine trout streams. *Journal of Wildlife Management*. 26:86–93.

Waters, T. F., 1964. Recolonization of denuded stream bottom areas by drift. *Trans. Am. Fish. Soc*. 93:311–315.

Waters, T. F., 1972. The drift of stream insects. *Annu. Rev. Entomol*. 17:253–272.

WDNR, 1970. *Reproduction and Early Life History of the Walleye in the Lake Winnebago Region*. Technical Bulletin 45. Wisconsin Department of Natural Resources, Madison, Wisconsin.

WDNR, 1994. *Fish Community Objectives for Lake Michigan*. Wisconsin Department of Natural Resources, Madison.

WDNR, 1995. *A Deterministic PCB Transport Model for the Lower Fox River Between Lake Winnebago and De Pere, Wisconsin*. Publication PUBL-WR-389-95. Wisconsin Department of Natural Resources, Bureau of Water Resources, Madison, Wisconsin.

WDNR, 1996. *Lower Fox River System Sediment Characterization – Sediment Quality Triad Assessment and Application of Sediment Quality Guidelines*. Sediment Management and Remedial Techniques Team, Madison, Wisconsin.

WDNR, 2001. *Technical Memorandum 7c: Recommended Approach for a Food Web/Bioaccumulation Assessment of the Lower Fox River/Green Bay Ecosystem*. Wisconsin Department of Natural Resources. January.

WDNR, 2002a. Little Lake Butte des Morts Watershed, LF06. Wisconsin Department of Natural Resources Website: http://www.dnr.state.wi.us/org/gmu/lowerfox/surfacewaterfiles/watersheds/lf06.html

WDNR, 2002b. Self-Help Lake Monitoring Annual Reports. Wisconsin STORET Database Website: http://www.dnr.state.wi.us/LakeSelfHelp/SearchOne.asp.

WDNR and EPA, 2001. *Proposed Remedial Action Plan, Lower Fox River and Green Bay*. Wisconsin Department of Natural Resources, Madison, Wisconsin and Green Bay, Wisconsin and United States Environmental Protection Agency, Region 5, Chicago, Illinois. October.

Weaver, M. J., J. J. Magnuson, and M. K. Clayton, 1997. Distribution of littoral fishes in structurally complex macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences*. 54:2277–2289.

Weber, J. J. and K. J. Otis, 1984. *Life History of Carp in the Lake Winnebago System, Wisconsin 131*. Department of Natural Resources Research, Madison, Wisconsin. December.

Westlake, D. F., 1975. Primary production of freshwater macrophytes. In: *Photosynthesis and Productivity in Different Environments*. Cooper, J. P. (ed). University Press, Cambridge. p. 189–206.

Wetzel, R. G., 1983. *Limnology*. Saunders College Publishing. Orlando, Florida.

Whillans, T. H. E., 1990. Assessing threats to fishery values of Great Lakes Wetlands. In: *Proceedings: International Wetland Symposium – Wetlands of the Great Lakes*. J. Kusler, R. Smardon (eds). The Association of State Wetland Managers, Niagara Falls, New York. p. 156–164.

Williams, D. D., 1981. Migrations and distributions of stream benthos. In: *Perspectives in Running Water Ecology*. Lock, M. A. and D. D. Williams (eds). Plenum Press, New York. p. 155–207. As cited in Taylor, B. and Z. Kovats, 1999. *Review of Artificial Substrates for Benthos Collection*. Prepared for Canadian Centre for Mineral and Energy Technology by Golder Associates, Ltd., Calgary, Alberta. Website: http://www.nrcan.gc.ca/mets/aete/reports/2_1_1.pdf.

Williams, D. D. and H. N. Hynes, 1976. The recolonization mechanisms of stream benthos. *Oikos*. 27:265–272.

Yount, J. D. and G. J. Niemi, 1990. Recovery of lotic communities and ecosystems from disturbance – A narrative review of case studies. *Environmental Management*. 14(5):547–569.